At its 2003 Annual General Meeting, Commission C12 of the International Union of Pure and Applied Physics (IUPAP) made a formal decision to establish an ad-hoc Committee on International Cooperation in Nuclear Physics (CICNP). The membership of CICNP included the Chair and Vice-Chair of C12, as well as the Chairs of NSAC and NuPECC and representatives of key laboratories world-wide. Considerable care was also paid to the geographic distribution of members, in order to ensure appropriate representation from the whole nuclear physics community.

The formation of this committee had been a topic of discussion within C12 since 1995 and perhaps even earlier. It was created to facilitate international cooperation within the nuclear physics community following the recommendations of the various committees that preceded it. The objectives of CICNP were:

- To promote international cooperation in the broadest sense with the construction and exploitation of the large nuclear physics facilities - those which are intended for use by a worldwide nuclear physics community.
- To organize meetings on a regular basis, which are open to all wishing to attend, for the exchange of information on future plans for new nuclear physics facilities, be it very large multi-disciplinary facilities or facilities intended to more regional use.
- To stimulate the organization of workshops and/or symposia to discuss the future of nuclear physics and the need for facilities for the various subfields: high energy heavy-ion beam facilities, radioactive-ion beam facilities, multipurpose hadron beam facilities, high energy electron beam facilities.
- It was also recognized that there was a need to discuss facilities which are clearly cross-disciplinary, like underground laboratories for particle, nuclear, and nuclear-astrophysics.

In accomplishing these objectives the committee was to document facilities under construction or being planned in terms of their anticipated performance parameters; to assess these anticipated performance parameters with regard to the requirements of the field; to evaluate the different facilities in terms of their complementarities and to indicate the areas of the field not covered but identified in the current science planning documents, like the NSAC Long Range Plan, the NuPECC Long Range Plan, and similar documents; and to recommend on the need for additional new facilities and for the expeditious use of the current facilities. The first Chair of CICNP, appointed by C12, was Anthony W. Thomas.

The creation of this ad-hoc committee was also presented at the IUPAP Council and Chairs Meeting in October, 2003. The IUPAP headquarters welcomed this proposal and suggested that it might become an official Working Group of IUPAP. This led to a formal proposal to that effect, which was approved at the October 2005 General Assembly in South Africa. The new IUPAP Working Group, WG.9, has the following Mandate (http://www.iupap.org/wg/):

1. provide a description of the landscape of key issues in Nuclear Physics research for the next 10 to 20 years
2. produce (maintain) a compendium of facilities existing or under development worldwide
3. establish a mapping of these facilities onto the scientific questions identified above
4. identify missing components that would have to be developed to provide an optimized,
5. explore mechanisms and opportunities for enhancing international collaboration in nuclear science
6. identify R/D projects that could benefit from international joint effort
7. serve as a source of expert advice for governmental or inter-governmental organizations in connection with efforts to coordinate and promote nuclear science at the international level
8. serve as a forum for the discussion of future directions of nuclear science in the broadest sense
9. document the cross disciplinary impact of Nuclear Physics and of nuclear facilities and identify mechanisms for expanding (fostering) cross disciplinary research

This booklet is the result of the first task which WG.9 has set itself. It is a compendium of those basic nuclear physics facilities world-wide which are considered genuine user facilities by management. As far as it has been possible the information is complete and accurate. However, the very nature of IUPAP means that participation is purely voluntary and in the case of a very small number of countries we have been unable to obtain information. In addition, apart from personal knowledge of the members of the committee it has been necessary to rely on the information provided by the facilities themselves.

In spite of the obvious difficulties this is probably the most comprehensive summary of the research facilities available to the international nuclear physics community that has been compiled. It has been supplemented by a brief outline of how these facilities relate to what the committee feels are the major questions facing us in key areas of nuclear science. We very much hope that the nuclear community will find this a useful resource and it will be widely distributed as well as made available on the world-wide web.

Anthony W. Thomas
Chair WG.9
July 9, 2007

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• Zeblon Vilakazi (Director i’Themba Laboratories, S. Africa)
• Wenlong Zhan (IMP-Lanzhou, PRoC)
This report is the culmination of an enormous amount of work by many people. I would like to thank all of the laboratory representatives who responded to us and helped to ensure the accuracy of the entries. It is also appropriate to acknowledge the efforts of all those members of WG.9 and C12 who worked hard to solicit information, contribute to the overview sections and provide quality assurance on the final document.

I would like to particularly thank Walter Henning and Wim van Oers for their tireless efforts to produce a high quality report on schedule. I also would like to thank Gabriele-Elisabeth Körner for her help with obtaining some of the laboratory information in this report. It is a pleasure to acknowledge the enormous amount of work that Susan Brown devoted to the preparation and the presentation of this document.

On behalf of the community I would also like to express appreciation to IUPAP for their support (including a financial contribution to printing costs) of this project.

Anthony W. Thomas
Chair WG.9
Jefferson Lab
July 9, 2007
Updated Version of IUPAP Report 41

One of the mandates of the IUPAP Working Group 9: ‘International Cooperation in Nuclear Physics’, as also confirmed by the OECD Global Science Forum, is to update IUPAP Report 41 on a regular scheduled time frame. IUPAP Report 41 was first published as a hard copy and as an electronic version in 2007. Since then additional individual nuclear laboratory descriptions have been added. Following the second Nuclear Science Symposium, which was held at INFN Laboratori Nazionali di Frascati, May 31 – June 1, 2013, also the Introduction to IUPAP Report has been updated with succinct synopses of the seven subfields of nuclear physics discussed at the Nuclear Science Symposium which give the more important science questions to be addressed in the coming five to ten years.

We would like to thank all who have contributed to this update of IUPAP Report 41.

Robert Tribble
Chair of IUPAP WG.9

Willem T. H. van Oers
Secretary of IUPAP WG.9
TRIUMF, December 1, 2013
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Executive Summary

Updated August 24, 2012, by Anthony W. Thomas (University of Adelaide)

Nuclear physics is driven by the challenge to understand the origin, evolution, symmetries, structure and phases of strongly interacting nuclear matter. This is a challenging mandate that requires a balanced program of experimental and theoretical effort to address a series of key questions. There is a broad international consensus on these more important questions as they are formulated in a very similar manner in both the Nuclear Science Advisory Committee (NSAC) report in 2007 and in the Nuclear Physics European Collaboration Committee (NuPECC) report in 2011. The five key questions and the major facilities where these questions can be answered are:

1) Can the structure and interactions of hadrons be understood in terms of QCD?

Nucleons are composite particles made up of quarks and gluons. Extensive investigation has revealed much about how the quarks are distributed and move within the nucleon and the 2004 Nobel Prize in Physics was awarded for the discovery of asymptotic freedom within the context of perturbative Quantum Chromodynamics (QCD). However, QCD is unsolved in the confinement regime where the quark coupling strength is too large to permit perturbative methods to be used. One of the central problems in nuclear physics remains the connection of the observed properties of the hadrons to the underlying theoretical framework of QCD. The solution requires advances both in theory and experiment. In a few specific cases, where chiral coefficients are well known, recent advances in lattice QCD, in combination with chiral perturbation theory, have allowed one to extrapolate full lattice simulations to physical quark masses, thus enabling a direct comparison with experimental observables. The objectives are:
- a tomographic view of the quarks and gluons and their motion within the nucleon.
- insight into the distribution of the spin of the nucleon as spin and orbital angular momentum of its constituents.
- a detailed understanding of how QCD gives rise to the properties of the lighter hadrons; and how these properties are modified when they are placed in a nuclear environment.

Experiments designed to make detailed comparisons with QCD predictions are high-priority endeavors for research at facilities across the USA, Japan, and Europe. In particular, J-PARC of KEK and JAEA, which is operating now and FAIR at GSI and the 12 GeV upgrade at Jefferson Lab, which will begin operations in the near term, were all designed (to varying degrees) to address this question in detail.

In addition one should mention the important program of study using colliding polarized protons on polarized protons at RHIC, the recently completed 6 GeV program at Jefferson Lab and the plans under development at Jefferson Lab and RHIC to extend the earlier work at DESY, namely the study of the structure of the sea of the nucleon. Jefferson Lab and RHIC, as well as CERN, are developing plans to extend these studies to the structure of the sea of atomic nuclei.
2) What is the structure of nuclear matter?

Understanding the properties of nuclei and nuclear matter is a formidable task, which has traditionally been approached in steps: from the basic equations of QCD through effective field theories to nucleon-nucleon interactions, few-body systems and very-light nuclei. Alternatively one may seek to determine an effective density dependent force and then exploit the many approaches used to describe nuclear structure, ranging from methods such as Green's Function Monte Carlo (GFMC) to the shell model and density functional theory. While calculations based on "realistic" nucleon-nucleon interactions, supplemented with phenomenological three-body forces, have achieved quantitative success in reproducing the features of light nuclei, detailed agreement is still lacking for heavier nuclei. There has recently been some progress in deriving density dependent effective interactions from quark models. The degree of complexity found in these problems is not restricted to the description of heavy nuclei but is common to the description of other complex systems, such as proteins.

The development of a comprehensive, predictive theory of complex nuclei is a key goal for nuclear physics. Worldwide this has driven the development of high-quality and multi-faceted radioactive beams, as these allow one to move from a one-dimensional picture, where the mass of the nucleus varies, to a two-dimensional picture where both proton and neutron numbers vary over a wide range. Rare isotope beams are obtained either through the well known ISOL process or through in flight fragmentation. There exists at present a plethora of small and large facilities of both kinds, the larger ones being NSCL at Michigan State University, ISOLDE at CERN, ISAC (I and II) at TRIUMF, and SPIRAL1@GANIL in Caen, France. The near-future facilities are BRIF and SLEGS in China, RIKEN in Japan, SPES in Italy, GSI-FAIR in Germany and SPIRAL2@GANIL in France. Still in the planning stage are EURISOL in Europe, HIAF and Beijing ISOL in China, KORIA in Korea and FRIB in the USA. These facilities are also engaged in studying current nuclear structure problems. The quest for the super-heavy elements is an ongoing effort at JINR in Dubna, GSI in Darmstadt, and RIKEN in Saitama.

3) What are the phases of nuclear matter?

Nuclei are an important manifestation of nuclear matter, since they make up 99.9% of the visible matter in the universe. But it is somewhat humbling to realize the preponderance in the universe of dark matter and dark energy. At the highest densities, yet at still rather low temperatures, the quarks making up the nucleons of nuclear matter may form a new state of nuclear matter, which is color superconducting. As the density rises (but before quark matter of any kind can form) one may also find a large fraction of the matter present is strange and one cannot yet exclude the possibility of kaon condensation. Nuclear matter can also be heated by absorbing energy in a relativistic collision. In this case 'nuclear temperatures' can reach values that represent the state of matter that existed during the first moments after the big bang. The quest for the so-called quark-gluon plasma (or phase transitions in hadronic matter) is an active field of study at international facilities such as GSI in Germany, the LHC at CERN (ALICE experiment), and RHIC in the USA.

4) What is the role of nuclei in shaping the evolution of the universe?

Primordial nucleosynthesis, nucleosynthesis that occurred during the cooling immediately following the big bang, gave rise to the primordial abundances of H, He, and Li. All other chemical elements in the universe were produced as a result of the nuclear reactions occurring in stars, during supernovae explosions, novae, neutron star mergers, etc. It is
another central objective of nuclear physics to explain the origin and abundances of matter in the universe, while nuclear astrophysics must address the many fundamental questions involving nuclear physics issues that remain. The latter include: the origin of the elements; the mechanism of core-collapse in supernovae; the structure and cooling of neutron stars and the presence of strange matter; the origin, acceleration, and interactions of the highest energy cosmic rays; and the nature of galactic and extragalactic gamma-ray sources. Nuclear astrophysics has benefited enormously from progress in astronomical observation and modeling. A new era in nuclear astrophysics has opened up with the advent of rare ion beam facilities dedicated to the measurement of nuclear reactions involving short-lived nuclides of particular relevance to astrophysics. These include measurements of the various nuclear capture processes and the determination of masses, half-lives, and structures of rare nuclei that occur in cataclysmic stellar environments. Most of the rare isotope facilities (mentioned in item 2), above) have or will have extensive research programs in nuclear astrophysics.

5) What physics is there beyond the Standard Model?

The forces and interactions that were in play in the early stages of the universe have shaped the cosmos as it is known today. Nuclear physicists have long studied the fundamental symmetries of the weak interaction, and probed the Standard Model with precision, low- and intermediate-energy experiments. While the Standard Model has proven remarkably resilient to these tests, there are a few indications of physics beyond the Standard Model. If the breakdown of the Standard Model is confirmed, this could constitute the first indication of super-symmetry, which offers a possible explanation of the dark matter of the universe. A new generation of experiments, designed to push the limits of discovery and precision, can be grouped as follows:

i. The universe has an obvious imbalance between matter and antimatter which the Standard Model is unable to explain. An essential ingredient in the possible solution of this enigma is the presence of new interactions which violate time-reversal-invariance (TRI) and charge conjugation/parity inversion (CP) (if one assumes CPT invariance). There is today a great deal of activity probing for a signal of TRI violation in the properties of mesons, neutrons, and atoms.

ii. Another key question is the nature of the "superweak" forces which disappeared from view when the universe cooled. The Standard Model, as stated above, is one of the better tested theories in physics, but still it is considered to be incomplete. Both nuclear and particle physics experiments are continually searching for indications of additional forces that were present in the initial moments after the big bang. High-energy experiments will probe the TeV scale directly, but high precision experiments at lower energies probe mass scales and parameter spaces not accessible at the high-energy accelerator facilities. Any deviation from the Standard Model discovered at the LHC, for instance, must be reflected in a corresponding rare interaction at lower energy. Jefferson Lab is a prime laboratory for such studies of probing the limits of validity of the Standard Model and of the physics beyond. Other approaches followed are atomic parity violation measurements for which trapping experiments at the rare isotope facilities are essential.

iii. Finally, the one area where the Standard Model has clearly broken down concerns neutrinos. The resolution of the solar and atmospheric neutrino puzzles by SNO and Super-Kamiokande has opened up the possibilities for further exciting discoveries in the neutrino sector, such as CP violation. A key question is the nature of the identified neutrino
oscillations (long baseline neutrino experiments, e.g. T2K). In this context one can contemplate the possibility of a neutrino factory. The observation of neutrinoless double beta decay would revolutionize the understanding of lepton number in the Standard Model and would determine the mass scale of the neutrino. Clearly, existing and future underground laboratories have an all-important role to play, searching for the decay of the proton, neutrinoless double beta-decay, and not to be forgotten dark matter!
1. Introduction

The atomic nucleus is the core of visible matter comprising 99.9 percent of its mass; its structure determines many facets of the world around us. Atomic nuclei are nature’s most abundant high energy-density substance. Nuclear processes fuel stars, determine stellar evolution, drive stellar explosions, and are responsible for the origin of the elements in nature. The subfield of nuclear structure, reactions, and nuclear astrophysics (NS/NA) attempts to measure, explain, and use nuclear properties and reactions to meet society’s scientific curiosity and needs. The relevance of this science spans the dimensions of distance from 10-15 m (proton’s radius) to 12 km (neutron star radius) and timescales from fractions of a second after the Big Bang to today, i.e., 13.7 billion years later.

Very recently a report from the U.S. National Research Council surveyed the past decade of accomplishments and the future prospects for nuclear science. Four very broad questions were used in that report to frame the field. Those questions serve as an excellent way to introduce modern nuclear science research and are reproduced here.

• How did visible matter come into being and how does it evolve?
• How does subatomic matter organize itself and what phenomena emerge?
• Are the fundamental interactions that are basic to the structure of matter fully understood?
• How can the knowledge and technological progress provided by nuclear physics best be used to benefit society?

The intellectual challenges for NS/NA are captured well in these four overarching questions. The specific challenge for NS/NA is to explain how atomic nuclei are created, how they behave, and how to use them for science and applications. Overcoming these challenges requires a deep understanding of the atomic nucleus. The vision of the field is to achieve this understanding by development and testing of a comprehensive theory of nuclei and their interactions that has predictive power and quantified uncertainties. This theory, informed by experimental observations of important properties for key nuclei will allow us, for example, to assess the fusion rates of light nuclei, model the properties of fission products of uranium and plutonium isotopes, trace the origin of the elements in the cosmos, and provide structural information for interpretation of fundamental symmetries experiments involving nuclei. Part of the challenge is to understand which nuclei are going to be the most interesting or important in realizing this vision, and then make them in the laboratory. Today, we have identified some of the important nuclei, such as those responsible for creation of about half of the heavier elements in nature, but we do not yet have the means to make them. An overview of the opportunities is given in the following sections.

Within the large territory of nuclei, with behaviors ranging from simple to complex, there are many intellectual connections and benefits to other fields of science. In addition to the discovery aspect, the basic research in this subfield often has direct bearing on many branches of science and societal relevance to national security, energy, medicine, and industry. These are discussed in detail in the section on applications. Opportunities to advance this field play a critical role in attracting and training the next generation of nuclear science leaders needed by our national laboratories, industry, and academia.
The experimental work in this area of nuclear science is carried out at national user facilities worldwide, as well as a number of small accelerator laboratories at universities and national laboratories. Experimental work is closely coupled with forefront developments in nuclear theory and computational tools made by researchers employing the nation’s top computational facilities. The breadth of the research requires multiple approaches with a variety of tools and techniques. The individual research groups are usually small, often involving many junior scientists and students who are responsible for all aspects of their research.

Our current understanding has benefited from technological improvements in experimental equipment and accelerators that have expanded the range of available isotopes and allowed individual experiments to be performed with only a small number of atoms. Concurrent improvements in theoretical approaches and computational science have led to a more detailed understanding and pointed toward which nuclei and what phenomena to study. However, to break current experimental barriers, NS/NA needs expeditious completion of new radioactive ion beam facilities (RIBFs) of the next generation (see Fig. 1). With those powerful facilities, the field has a clear path to achieve its overall scientific goals and answer the overarching questions.

2. The origin and evolution of atoms and nuclei
The subfield of NS/NA participates in answering the overarching question “How did visible matter come into being and how does it evolve?” Nuclear astrophysics studies the nuclear and chemical evolution of the Universe since the first minute of the Big Bang. By addressing the nature of the nuclear force, the mechanism of nuclear binding, and nuclear decays, the fields of nuclear structure and reactions describe the microphysics of this evolution.
2.1. Star “Stuff”

Nuclear astrophysics is broadly concerned with nuclear processes in all astrophysical environments, giving us the tools to understand the nuclear and chemical evolution of the Universe, fundamental physics, and astrophysical observations taken with large telescopes and neutrino detectors. The build-up to the present mix of elements from the soup of free nucleons early in the Big Bang has occurred through complex nuclear reaction chains in many generations of stars. Carl Sagan summarized this remarkable series of events with his famous expression: “We are made of star stuff.” Among the open questions that will guide nuclear astrophysics in the coming decade are: How did the elements and isotopes originate in the cosmos? What makes stars explode as supernovae, novae, or X-ray bursts? What is the nature of neutron stars? What can neutrinos tell us about stars? What were the first stars in the Universe like? Answering these questions requires understanding intricate structural details of thousands of stable and unstable nuclei, see Fig. 2.

A particularly significant role of nuclear astrophysics is to develop new probes for nuclear processes that are occurring in the deep cores of stars, not otherwise accessible through traditional astronomical techniques. This ranges from the observation of neutrinos from our sun and nearby supernovae by neutrino detectors located deep underground to satellite-based gamma-ray detectors mapping the distribution of radioactive elements in our galaxy. Observations of neutrinos originating from the solar core complement helioseismological measurements of the surface of the Sun. The analysis of stellar pulsations provides information on the temperature conditions of the inner layers of massive stars during the later phases of their evolution.

Figure 2: Nuclear landscape and nuclear astrophysics
A broad experimental portfolio has been developed to advance our understanding of the life and death of stars and to benchmark the ever more complex computer simulations of these events.

Nuclear reactions that determine the stellar energy production, lifetime, and the chemical composition are have extremely low cross sections and their study is handicapped by cosmic ray backgrounds. While these measurements are being pursued at deep underground laboratories, another frontier is the study of nuclear processes that drive stellar explosions. These explosions occur on a rapid timescale of a few seconds. Radioactive nuclei formed in the explosion cannot decay within this short period and become part of the sequence of nuclear reactions that occurs far beyond the limits of nuclear stability. A study of these reactions and of the nuclei along the reaction path provides fundamental insight into the nature of these processes, the rapid timescale of the explosion, the associated energy release and, of course, nucleosynthesis. As discussed below, experimental data from next-generation RIBFs will make it possible to identify the specific nature of the nuclear reaction pathway during an explosive event and, in turn, through comparison with the emerging abundance distribution, specifics about the astronomical site and conditions during the explosion.

To explain the process of creating new atomic nuclei (nucleosynthesis), experiments will investigate the most important nuclear reaction chains in stellar explosions associated with different astrophysical environments. Two examples illustrating this potential are X-ray bursts and supernovae. The first is driven by accretion of hydrogen fuel in binary star systems onto a compact star, either a white dwarf or neutron star. These events are observed as novae or X-ray bursts, respectively, and are thermonuclear explosions of the accreted hydrogen fuel on the surface of the compact star. The second kind of explosion, supernova, is triggered by the collapse of the inner core of a massive star to a neutron star, a process that initiates a shock wave that traverses the outer layers of the star, generating conditions that lead to multiple nucleosynthetic pathways behind the emerging shock. Similarly extreme conditions are associated with the merger of two neutron stars.

X-ray bursts are powerful thermonuclear explosions that within a few seconds transmute the low-atomic-mass material in the atmosphere of the neutron star into a distribution of heavy elements up to mass 100 by the rapid-proton-capture (rp) process, a sequence of rapid proton capture reactions and β-decays responsible for the synthesis of many proton-rich heavy isotopes. The timescale of the burst, the endpoint, and the final abundance distribution depend upon the nuclear reaction and decay rates along the rp-process path. Measurements of the reaction cross sections require higher beam intensities than are available at existing RIBFs. The next-generation RIBs will provide the necessary intensities for most of the critical rp-process nuclei). Therefore, for the first time, nuclear astrophysicists will be able to directly study radiative capture reactions to determine ignition conditions, timing, and endpoint conditions in these thermonuclear explosions.

How were the neutron-rich elements heavier than iron made? These heavy elements are produced either by slow neutron capture reactions, the s-process that takes place during helium and carbon burning phases of stellar evolution, or by rapid neutron capture reactions, the r-process that requires a much higher temperature and density environment. The masses (binding energies) and the lifetimes of nuclei along the r-process path are the most important microscopic parameters for theoretical simulations. These inputs are currently taken from extrapolations based on theoretical models. From first experiments at existing facilities on
isotopes just reaching the r-process path we know these extrapolations are highly uncertain and new experiments can lead to substantially different results.

New constraints are coming from large aperture observatories such as the Hubble Telescope and Subaru. Observations of early-generation stars indicate a heavy-element abundance distribution, which matches the patterns, albeit not the absolute abundances, of the r-process element abundance distribution in our Sun. This strongly suggests that there is a unique site for the r-process. The nature of the actual astrophysical site of the r-process has been a matter of fierce scientific debate for many decades. Both the emerging shock front of a supernova and the clash of merging neutron stars provide conditions for an r-process to occur. Model simulations of both events provide distributions that match the main features of the observed one. Nuclear physics data are crucial for making detailed predictions and to determine potential features for identifying the actual site. The r-process is a critical issue in which observational, modeling, and experimental data are essential to reach a solution to an important and long-standing astronomical problem.

There have been heroic efforts over the last decades to expand theoretical and experimental frontiers in an effort to explain r-process nucleosynthesis. The increasingly complex models of (i) supernova explosions, taking into account detailed radiation/hydrodynamics, neutrino and nuclear physics, and magnetic and rotational effects, and (ii) merging neutron stars both motivate the pursuit of measurements beyond the present limits of experimental facilities. Next-generation RIBFs will provide the experimental reach and mass and lifetime data necessary to test the most important parameters of r-process simulations. They will test the suitability of the various nuclear models presently used for r-process simulations and will provide new benchmarks for the astrophysical models proposed for the actual r-process sites.

Next-generation RIBFs will also be important for understanding various astrophysical objects. Neutron stars serve as a good example. The cooling behavior of transient neutron stars is determined by the energy budget of the nuclear processes on the ashes of the rp-process. Electron-capture reactions, driven by the ever-increasing density of the neutron-star crust, drive the abundance distribution to the neutron-rich side. Such electron-capture reactions change the internal energy budget in the crust and affect the cooling behavior of the neutron-star crust matter. These electron-capture processes can be studied by means of charge-exchange reactions on neutron-rich isotopes.

2.2. The Grand Nuclear Landscape

What combinations of neutrons and protons can form an atomic nucleus? The answer has important consequences for nuclear structure and astrophysics. The quest for the limits of nuclear binding is closely connected to the roadmap to a comprehensive theory of all nuclei and, as discussed earlier, to the question about the origin of elements in the universe. The territory of nuclear existence is currently unknown, but likely much more vast than we have explored so far. Only 288 of several thousand nuclides, or isotopes, known to inhabit the nuclear landscape are either stable or practically stable (i.e., have half-lives longer than the expected life of the solar system). By moving away from the region of stable isotopes, by adding nucleons (either neutrons or protons), one enters the regime of short-lived radioactive nuclei, which disintegrate by emitting beta and alpha particles, or split into smaller parts through the process of spontaneous fission. Nuclear existence ends at the drip lines, where the last nucleon is no longer bound to the others. Remarkably, the neutron-rich boundary is known only up to oxygen (Z=8). The superheavy nucleus with Z=118, A=294 marks the current upper limit of nuclear charge and mass. Those borders define the currently known
nuclear territory – the nuclear landscape proper. Today, about 3000 nuclides are known to us, but the number of those which have been well characterized is much less.

Nuclear theorists predict the existence of more than double the number of known nuclei. As discussed earlier, while most of the predicted nuclei may never be seen, their influence will certainly be noticed, as the astrophysical processes that generate many heavy elements occur relatively close to the driplines. Explaining how the atomic nucleus ticks, will require building a comprehensive model that describes quantitatively and predictably this quantum system, and is grounded in the fundamental interactions at play between its constituents. Such a theoretical “bottom-up” description can be gained from an accurate solution of the nuclear many-body quantum problem, but this is a formidable challenge that can only be attacked with experiment and nuclear theory working in concert. To arrive at a comprehensive understanding of nuclei will require new insights from experiments on rare isotopes previously not available that will guide new theoretical developments. Accurate solutions of the strongly interacting nuclear systems will yield new insights and the ability to calculate phenomena, processes, and states of matter that are difficult or impossible to measure experimentally, such as the crust of a neutron star or the core of a fission reactor.

The territory of very neutron-rich nuclei is where most of the action is in NS/NA research (r-process studies, probing the neutron drip line, and – generally – studying properties of neutron-rich matter. Experimental exploration of this vast area is extremely challenging because of the very low production rates in studies involving the fragmentation of stable nuclei and the separation and identification of the products. Staking out the nuclear landscape also opens up opportunities to design nuclei with specific properties adjusted to our research and application needs.

There is another limit that challenges our present understanding of nuclei. What are the heaviest nuclei and atoms that can exist? Do very long-lived “superheavy” nuclei with atomic numbers greater than Z=106 exist in nature? While it was recognized long ago that, in spite of the huge electric repulsion between all those protons, the binding that comes from motion of protons and neutrons in regular orbits (“shells”) could tip the balance in favor of their existence, precise calculations are difficult. The recent progress in this field came from the realization that new elements can be synthesized by using targets of very heavy elements such as berkelium with neutron-rich beams. This novel approach was used to create nuclei with Z = 113-118, having increased lifetimes, in accord with theoretical expectations. Another exciting avenue is offered by atom-at-a-time chemistry studies of the superheavy elements. Since atomic relativistic effects increase rapidly with atomic number, the superheavy region is expected to produce significant deviations from the organizational principles captured by the existing periodic table of the elements. Recently, by using individual atoms of Copernicium (Cn, Z = 112) it has been possible to place Cn in group 12 of the periodic table, under Mercury, Cadmium and Zinc.

The borders of the nuclear existence do not end at the proton and neutron driplines and the superheavy region: the territory of neutron-proton matter is much broader. The grand nuclear landscape includes the extended nucleonic matter, such as that found in the crust of neutron stars. Understanding these systems is also part of the challenge for NS/NA.

3. The Simplicity of Complexity

Complex systems often display surprising simplicities; nuclei are no exception. It is remarkable that a heavy nucleus consisting of hundreds of rapidly moving protons and neutrons can exhibit a regular behavior, reflecting collective properties of many nucleons
The resulting emergent phenomena discussed in this report—such as appearance of nucleonic shells, collective rotation, superfluidity, and phase transitions—are not sensitive to the details of the interactions between the constituent particles. The relevant overarching question addressing the origin and nature of the nuclear emergent behavior is “How does subatomic matter organize itself and what phenomena emerge?” This perspective—focused on a highly organized complex system exhibiting special symmetries and regular patterns—is complementary to the “bottom-up” view discussed in the previous section.

3.1. Fragile Nucleonic Shells

One of the paradigms of nuclear structure is the shell model of the atomic nucleus, in which the motion of each neutron or proton is governed by a common force generated by all of the other nucleons. Thanks to this common force, similar to an electron’s motion in an atom, nucleonic orbits bunch together in energy, thereby forming shells, and nuclei having filled nucleonic shells (nuclear ‘noble gases’) are exceptionally well bound. The numbers of nucleons needed to fill each successive shell are called the magic numbers: The traditional ones are 2, 8, 20, 28, 50, 82, and 126. One of the most dramatic series of discoveries with current rare isotope research has been the recognition that the traditional benchmark magic numbers are not the immutable cornerstones they were thought to be for over half a century during which nuclei were studied within a rather restricted range of neutron-to-proton ratio. For instance, the magic number N = 20 disappears in magnesium, and the magic number N = 28—in silicon. These discoveries demonstrate the need for dramatic revision of the textbook knowledge of the motion of protons and neutrons inside the nucleus. In the superheavy region, there is no consensus with regard to what should be the next magic nucleus beyond lead-208 (82 protons and 126 neutrons). Calculations suggest fairly broad regions of enhanced stability, but we may well find surprises as we get there.

Excellent tests of nuclear shells were offered by recent studies of the proton-magic nickel (Z=28) and tin (Z=50) isotopes. The short-lived isotopes nickel-78 (N=50), tin-100 (N=50), and tin-132 (N=82), are expected to be rare examples of new doubly-magic heavy nuclei. While tin-132 was shown to behave as a good doubly-magic nucleus, the data around tin-100 and nickel-78 have led to surprises. The new structural information indicates that poorly understood forces that depend on the neutron-proton imbalance, and the poorly known forces involving three nucleons, may be in play. An important consequence of shell variations far from stability is their influence on astrophysical processes and on stellar nucleosynthesis. Progress will only be achieved by measuring properties of rare isotopes in key regions of the nuclear chart. Such structural data are an essential guide: they will help constrain the essential interactions, many-body correlation effects (such as nucleonic pairing, or superfluidity), and quantify the role of a very poorly understood effect found in weakly-bound nuclei—the so-called particle continuum.

3.2. Neutron Rich Matter in the Cosmos and in the Laboratory

What is the nature of nucleonic matter consisting of a huge number of nucleons, such as that in the crust of neutron stars composed almost entirely of neutrons? To explain the nature of neutron-rich matter across a range of densities, an interdisciplinary approach is essential in order to integrate low-energy nuclear experiments with astrophysical theory, nuclear theory, condensed matter theory, atomic physics, computational science, and electromagnetic and gravitational-wave astronomy.
Protons and neutrons in atomic nuclei near the neutron-drip line where the nuclear binding ends experience a very different environment than their cousins in stable nuclei. This results in drip-line nuclei having a very different character than we are used to. In light nuclei, the weak binding can lead to the formation of a diffuse “halo” of neutron matter surrounding the more densely populated nucleus. In heavier neutron-rich nuclei, the excess of neutrons collects at the nuclear surface creating a “skin”, a region of weakly bound neutron matter that is our best laboratory access to the diluted matter existing in the crusts of neutron stars.

Figure 3 illustrates the multi-disciplinary nature of the quest for understanding of neutron-rich matter on Earth and in the Cosmos. It shows the mass-radius relation for a neutron star predicted by various theoretical models. The typical mass of a neutron star is about 1.4 solar masses, and the typical radius is thought to be about 12 km. One of the main science drivers of RIBFs is the study of a range of nuclei with neutron skins three or four times thicker than is currently possible. JLab uses a faint signal arising from parity violation induced by the weak interaction to measure the radius of the neutron distribution of stable lead and calcium nuclei. Studies of neutron skins in heavy nuclei, and investigations of high-frequency nuclear oscillations and intermediate energy nuclear reactions with a range of proton and neutron-rich nuclei will help pin down the behavior of nuclear matter at densities below twice typical nuclear density $r_0$. The relevant area open to these studies is indicated in light blue in Figure 6. At higher densities relativity and the observation of a nearly two solar mass neutron star places severe constraints on the relationship between the pressure and density of nuclear matter, i.e., the nuclear matter equation of state.

4. Tests of Fundamental Symmetries

By producing isotopes with enhanced sensitivity to fundamental symmetries, opportunities — complementary to other sciences — are provided for discovering physics beyond the Standard Model. In this way, this part of the NS program addresses the overarching question: “Are the fundamental interactions that are basic to the structure of matter fully understood?”

The “superallowed” beta-decays of nuclei in which both the parent and daughter nuclear states have zero angular momentum and positive parity are a case in point. The main assumption behind the current theory is that the weak force is universal for the complete panoply of subatomic particles. To check this assumption, atomic nuclei proved to be the key. Of thousands of different isotopes undergoing beta decay, a handful of rare isotopes with similar numbers of protons and neutrons are the best laboratory to study the universal strength of the weak force. The important advance came when the results of combined nuclear measurements worldwide, augmented by theoretical corrections due to isospin
breaking, showed that a key part of the weak force is the same within 1 part in 10 thousand for the 13 different nuclear decays studied. Future measurements in heavy nuclei with A>62, where the theoretical corrections are largest, will be helpful in still reducing the remaining uncertainty.

As discussed in the section on fundamental symmetries, measurement of an electric dipole moment (EDM), which separately violates parity and time-reversal invariance, is one of the crucial probes of physics beyond the Standard Model. Heavy radioactive atoms hold promise as a sensitive place to search for EDMs. The EDM is induced by the interaction of the electrons with the nucleus. An enhancement of order 100-1000 (or more) is possible in nuclei, which have pear-like shapes, such as radium-225. One of the near-term goals of the field is to identify the best candidates for enhancement. Next-generation RIBFs will provide at least an order of magnitude greater sensitivity than projected for current experiments.

5. NS/NA Theory

An understanding of the properties of atomic nuclei and their reactions is essential for a complete nuclear theory, including an explanation of element formation and the properties of stars, and for present and future energy, defense, and security applications. This requires a coherent picture across many energy scales, all the way from the interactions between nucleons to the extremely deformed shapes heavy nuclei achieve as they fission into lighter fragments. At the shortest distance scale, the nucleon-nucleon interaction is governed by the underlying forces between quarks and gluons. Currently, the parameters characterizing nucleon-nucleon interactions are primarily determined from experiment. The lattice QCD calculations will be particularly useful for those parts of the interactions that are difficult to address experimentally, such as the forces encountered by three nucleons approaching each other closely.
The physics of light nuclei can be studied directly with nuclear interactions and associated currents by using large-scale computing and ab-initio approaches that solve for nuclear structure and reactions directly from the underlying nuclear interactions. These simulations evaluate the quantum evolution of neutrons and protons at low energy similar to the way lattice QCD studies the evolution of quarks and gluons.

Within the past few years it has become possible to directly study excited states in light nuclei that resemble clusters of alpha particles, such as the low-lying excited “Hoyle” state in carbon-12. This state is essential for our existence as it governs the nucleosynthesis of carbon in stars. Important progress has also been made in relating structure of nuclei to their decays and reactions, allowing all those features to be computed simultaneously from nuclear interactions. Recent examples include analysis of scattering in light nuclei, providing crucial input for experimental fusion studies; computation of the long lifetime of carbon-14, used in radiocarbon dating; and determining the mass-radius relation for neutron stars. Ab initio methods are now reaching into the realm of medium-mass nuclei like oxygen and calcium, and are starting to probe the properties of the very neutron-rich isotopes.

The celebrated nuclear shell model (or configuration interaction method), in which the complex nucleus containing many protons and neutrons is approximated by a small number in interacting nucleons, can be used to make detailed studies of nuclear structure in limited regions of the nuclear chart. Calculations of nuclear properties and reactions in ab-initio and configuration interaction approaches are critical not only for an understanding of nuclei, but are increasingly important for interpreting nuclear experiments probing physics beyond the Standard Model and understanding the role of nuclear dynamics in astrophysics.

For larger nuclei and fission, density functional theory plays a critical role. It describes the properties of nuclei in terms of the neutron and proton distributions inside the nucleus. This theory is directly tied to experimental data and to ab initio theories of neutron-rich nuclei and inhomogeneous neutron matter. Modern nuclear density functional theory provides an excellent characterization of global nuclear properties including binding energies, radii, and shapes. Density functional theory is also being used to address the dynamics of fission, the structure of nuclear states with extreme angular momenta, and superheavy nuclei at the extremes of mass and charge.

The roadmap for this area, shown in Fig. 4 involves the extension of ab initio and configuration interaction approaches all the way to medium-heavy nuclei, and the quest for a universal interaction in the nuclear density functional theory that will allow description of all nuclei up to the heaviest elements. The direct coupling from nucleon-nucleon interaction scales (~100 MeV) to nuclear binding scales (~1-10 MeV) to collective excitation scales (<1 MeV), facilitated by effective field theory, provides a coherent picture of the structure and dynamics of all nuclei as nucleonic matter found in astrophysical environments, including neutron stars and supernovae. To realize this vision, the properties of rare isotopes are an essential guide. For example, they will help constrain the poorly known, but crucial, interactions that depend on the neutron-to-proton imbalance, elucidate the role played by three-nucleon forces, and quantify the impact of low-lying decaying and scattering states on the structure of weakly bound nuclei. Next-generation RIBFs will be essential for gaining access to key regions of the nuclear chart where the measured nuclear properties will challenge established concepts and highlight shortcomings and required modifications to current theory.

The coupling between ab initio and density functional theories has also been critical
addressing related problems extending beyond nuclear physics. Nuclear theorists have provided some of the most accurate calculations of the zero- and finite-temperature properties of a "unitary" gas of cold Fermi atoms and applied their nuclear methods to nano-scale superconducting metallic grains.

A major accomplishment of 20th century nuclear physics was to relate virtually all astrophysical phenomena to microscopic nuclear physics. In the past five years, new developments in nuclear astrophysics in the observational, theoretical, and computational areas, have been dramatic. Observationally, the recent discovery of a nearly two-solar-mass neutron star, combined with extraction of the mass/radius relationship from astrophysical observations, have placed very severe restrictions on the equation of state of cold and dense hadronic matter. These observations are quite consistent with microscopic theories of the nuclear equation of state, and are beginning to yield detailed information on the difference between properties of nuclear matter with equal numbers of neutrons and protons and pure neutron matter. Observations of neutron star cooling are also transforming the field, providing evidence for the onset of neutron superfluidity. Anticipated observations of gravitational waves from neutron star mergers and unique data on very neutron-rich nuclei from RIBFs can yield much more information, potentially further constraining the equation of state of dense hadronic matter.

Nuclear theory and computational physics, coupled to experiment and observations, are playing increasingly key roles in nuclear astrophysics. Computational developments have also been dramatic, fundamentally altering our picture of core-collapse supernovae. During the past five years, studies of these supernovae in three spatial dimensions have emerged to supersede the previous more limited capabilities in two dimensions. These improved calculations are radically transforming our views of the importance of instabilities and turbulence to the explosion mechanism, as well as of their character, yielding insights not available previously. New codes have also enabled realistic whole-star models of thermonuclear supernova explosions (Type Ia's), including the deflagration-to-detonation transition. The first detailed multi-dimensional stellar evolution calculations have also been published, going well beyond traditional spherical models that employed ad hoc convection theory. New physics issues, including coherent neutrino oscillations, are being addressed, with the potential to have an important impact on both the microphysics (e.g., the neutrino hierarchy) and the macroscopic physics (e.g., the nucleosynthesis) of core-collapse supernovae. Recently, the first neutron-star merger simulations in full general relativity with magnetic fields have been completed and it appears possible that these mergers could play a significant role in the synthesis of the heaviest elements.

6. Breadth and Relevance
The subfield of NS/NA has relevance to many branches of science and technology beyond the importance to astronomy, astrophysics, and fundamental symmetries discussed earlier. The deep connections of the nuclear many-body problem to the physics of complex systems that permeate modern science are as old as the field itself. Among many examples, prominent ones are: superfluidity, superconductivity, collective excitations, symmetry-breaking phenomena, phase-transitional behavior, and chaos. Of particular importance are the connections to cold fermion atomic condensates, which share many common features with neutron matter. Next-generation RIBFs, with their potential to explore weakly-bound nuclei with a large proton-to-neutron imbalance, will offer many unique opportunities for interdisciplinary research. Study of nuclei near the driplines, neutron-rich nuclei of mid- to heavy mass, and nuclei along the N=Z line will provide the necessary experimental input to
gain a quantitative understanding of nucleonic superfluidity – probed through a variety of reactions that add or subtract pairs of nucleons. The understanding of the structure and decays of rare isotopes, will lead to important progress in the general quantum science of open and marginally stable systems.

More broadly, low-energy research with rare isotopes will provide important benefits to society. In this way, this field answers the overarching question “How can the knowledge and technological progress provided by nuclear physics best be used to benefit society?” Rare isotopes are used in a wide variety of applications ranging from medical diagnostics to the tracing of groundwater migration patterns. They serve as sensitive probes in materials science studies of nanoscale devices and mechanical wear in novel materials. Their properties are relevant to new, safer nuclear reactors with less waste produced, based, for example, on thorium or other technologies. The IAEA has pointed out that data on decay heat are needed to optimize these designs and safety measures. For human health, the use of radioisotopes in medical imaging and therapy has impacted the lives of millions of patients worldwide. New medical diagnostics and treatments enabled by ready access to a wider range of isotopes could be transformative.
This is an exciting time for hadronic nuclear physics. There is a candidate for a fundamental theory of the strong interaction, namely Quantum Chromodynamics (QCD). In the high energy or short distance regime it has been thoroughly tested but the confinement regime remains a challenge. As was indicated already previously, the present decade will see a concerted effort to explore the consequences of non-perturbative QCD (the form of QCD applicable for strong binding), primarily using lattice QCD, while at the same time exploiting new experimental facilities and techniques to test those predictions. Three major new facilities, J-PARC (now in operation) in Japan, FAIR in Germany as well as the 12 GeV Upgrade at Jefferson Lab, slated to be completed in 2013, have been designed to answer this challenge.

The first great challenge to be addressed is the origin of confinement, that is, why free quarks have never been observed. This is connected in a fundamental way with the nature of the QCD vacuum, a complex medium of quark and gluon condensates and non-trivial topological structure. A key to unraveling this mystery experimentally is the prediction that within QCD one should find so-called exotic mesons (called hybrids and glue balls), in which gluons play more than a binding role, actually contributing to the observed quantum numbers in a characteristic way. The experimental search for these exotic mesons will be focused on two major new experimental facilities over the present decade – the GlueX experiment at Jefferson Lab, upgraded to 12 GeV in order to have the necessary energy reach, and the anti-proton storage ring at the new FAIR facility at GSI which will allow the high resolution exploration of charmed, exotic mesons. These two new facilities complement each other in that the latter will explore the nature of confinement in a heavy quark system, where a model invoking a flux-tube picture is perhaps a reasonable starting point, while the former will focus on light, relativistic quarks, for which it is much more difficult to construct a simple physical picture at present.

Next one faces important and fundamental questions regarding the structure of the proton and neutron. In more than 30 years since the discovery of scaling, in deep inelastic scattering at SLAC, it has not been possible to determine experimentally how the proton’s momentum is distributed onto its valence quarks. The behavior of the ratio of down to up quarks, as the quark momentum changes (as a quantity called Bjorken x approaches 1), is a crucial test of the role of correlations in the motions of pairs of quarks versus processes involving independent hard scattering in the proton. Another key question relates to the ‘spin crisis’ which first emerged in the 1980’s and has not yet been resolved. Naively one would think that the spins of the quarks in the nucleon would simply add to yield the spin of the nucleon. But this is not the case and the resolution of this question is one of the most intriguing and
important questions in the study of hadron structure. The question is how the proton spin is distributed amongst the valence quarks, the sea of quark-antiquark pairs, and their orbital motion. Two complementary techniques, semi-inclusive deep inelastic scattering studies at Jefferson Lab and the Drell-Yan process studied at RHIC will enable a complete characterization over the next decade. A closely related issue is whether gluons and their orbital motion also contributes significantly to the proton’s spin. The ongoing COMPASS experiment at CERN and the high energy Drell-Yan studies at RHIC show that most gluons may indeed play a role, but as yet the results have sizable uncertainties. Only a future electron-ion collider can resolve the gluonic contribution.

New experimental facilities offer new ways to explore familiar problems – sometimes with surprising results. The ability at Jefferson Lab to separate electric and magnetic form factors of the nucleon, by studying recoil polarization (rather than using the traditional Rosenbluth separation), has led to a dramatic change in the picture of the proton charge distribution. With the 12 GeV upgrade of CEBAF at Jefferson Lab, accurate and reliable measurements of both the electric and magnetic form factors of the proton and neutron can be extended to distance scales a factor of two smaller than currently possible. That is, measurements can be made of structure in the nucleon at distance scales much smaller than the nucleon itself, thereby probing the inner structure. By adding precision measurements of parity violation one can isolate the individual contributions of the u, d, and s quarks to these form factors – following pioneering work at MIT-Bates, MAMI-Mainz, and Jefferson Lab. Data on nucleon form factors in the time-like region are largely incomplete, and unfortunately will remain so for the foreseeable future.

Recently there has been tremendous interest in a new set of physical observables, the Generalized Parton Distributions (GPDs), which offer a three-dimensional (or tomographic) view of the internal structure of hadrons and, eventually, nuclei. The CLAS 12 detector at Jefferson Lab has been designed to explore the proton GPD’s across the entire valence region, while allowing sufficient overlap with the excellent work already done at smaller x at SLAC and reaffirmed in HERA and with Hermes at DESY. A particularly important milestone is the determination of the orbital angular momentum carried by the u and d valence quarks. This is a key element of the question how the proton’s spin is made up as discussed earlier. One may also hope to investigate the GPD’s by applying them to the analysis of exclusive antiproton-proton annihilation into two photons at large energy and momentum transfer. It is proposed to measure crossed channel Compton scattering and the related exclusive annihilation process with various final states (scalar meson, vector meson, or lepton pair) at FAIR.

Spectrum of mesons (as anticipated by lattice calculations as well as QCD-inspired modeling) in the mass range of 1.5 to 2.7 GeV. Those nonets with JPC quantum numbers that cannot simply be qq systems (often called "exotic") are labeled in red on the right.
There are further plans at FAIR to obtain polarized antiproton beams at the HESR in the future. It is argued that the quark transverse polarization is most accessible via Drell-Yan lepton pair production in antiproton-proton collisions, with the transverse distribution of valence quarks appearing at leading twist level and the cross section containing no unknown quantities besides the transversity distributions themselves.

A common theme across modern nuclear physics is the effect of a change of energy or baryon density on the QCD vacuum and the hadrons which may live in it. Studies at GSI have already yielded important information on the change of pion properties with baryon density. There are many theoretical predictions of changes of baryon and vector meson masses and other properties with density and temperature which must be tested experimentally. An array of techniques ranging from hadronic atom formation to antiproton annihilation in nuclei to the spin correlation parameters in quasi-elastic electron scattering will be applied to these issues over the next decade. Again the three new hadronic flag-ship facilities, FAIR, J-PARC, and Jefferson Lab with its 12 GeV upgrade, will carry the prime responsibility.

A particularly fundamental question of interest to both the nuclear structure and nuclear astrophysics communities are the origins of phenomena such as the observed ‘saturation’ of nuclear binding within QCD: that is the total binding energy of nuclei does not simply increase linearly with the number of nucleons, suggesting some kind of screening or reduction in nuclear interactions over the extended size of nuclei. Great progress has been made in understanding the stable nuclei in terms of effective two- and three-body forces, derived either phenomenologically or through modern effective field theory based on the symmetries of QCD. A truly microscopic understanding of the origins of these effective descriptions at the quark and gluon level would allow one rather more confidence in extending theories to regimes of density or neutron-proton asymmetry for which data are not yet available – for example at the densities found in the core of neutron stars or in nuclei with highly asymmetric numbers of neutrons and protons. Some progress has been made in relating the widely used Skyrme force to the quark-gluon level description of nuclei and this work needs to be continued. However, most importantly, this consideration points to the experimental challenge of measuring the changes

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The Generalized Parton Distributions are expected to yield a true three-dimensional picture of hadron structure for the first time.

Hadron substructure may be intimately connected with the manybody forces needed to understand nuclear structure.
of the properties of hadrons immersed in a nuclear medium, discussed above, especially important.
QCD and Quark Matter

Updated November 19, 2013, by Berndt Mueller (BNL)

The fundamental interactions of nature are described by theoretical models called gauge theories. Quantum Chromodynamics (QCD), the theory of strong interactions, is such a theory, with just a small number of parameters to be determined from experiment. It is, however, difficult to compute the manifestations of QCD in nature except in the high momentum or short distance limit, in which the effective coupling is weak and where the perturbative approach is extremely successful. The spectrum and structure of strongly interacting particles is not calculable in this approach. Tools for understanding this structure include experiment and computer simulations of QCD. The important questions about QCD that can be accessed with these tools may be formulated as follows:

1) **What are the phases of strongly interacting matter and what roles do they play in the cosmos?**

2) **What is the role of gluons in nucleons and nuclei?**

3) **What determines the key features of QCD; can they be understood as manifestations of holographic duals described by gravity or string theory?**

4) **Can the study of QCD vacuum fluctuations at high temperature illuminate other early-universe processes, such as the one responsible for the matter-antimatter asymmetry?**

5) **How are the unique properties of QCD manifested in unusual properties of strongly interacting matter?**

![Fig.1: Anticipated phase structure of hadronic matter](image)

Gauge theories describing other fundamental interactions raise similar questions, and presumably the phase structure of each played its role in the very early development of the Universe. The case of QCD is special, because it can be studied experimentally. Based on the
results of lattice gauge theory simulations, the transition from hadrons to a quarks-gluon plasma occurs at $T \sim 160$ MeV, which is low enough to be studied in the laboratory. (This is not the case for the electroweak gauge theory, where symmetry breaking occurs at $T \sim 100$ GeV, out of experimental reach.)

The experimental approach to the study of strongly interacting matter at very high temperatures involves collisions of hadrons at very high energy. The study of the properties of dense, many-body systems—implicit in most of the questions above—requires a large volume of high energy density matter. Thus, the fundamental questions about the physical states of strongly interacting matter are addressed in the laboratory by studying heavy ion collisions at relativistic energies.

In order to gain new understanding of QCD from the interaction of relativistic heavy ions, one needs directly comparable data sets from systems of various sizes, different energies and different experimental probes. These ancillary data sets provide “baselines” against which the largest volume, highest temperature, reactions can be compared. Thus a fundamental and systematic study of QCD requires data on nucleus-nucleus, proton-nucleus (or deuteron-nucleus), as well as proton-proton collisions, all at comparable nucleon-nucleon center of mass energies, and preferably in the same detector systems. Hard processes, which can be accurately calculated in proton-proton collisions using perturbative QCD, can then serve as calibrated probes of the medium created in collisions involving nuclear beams. Addressing many of the questions above also requires data from high energy interactions of hadrons with non-hadronic probes, e.g., deep inelastic scattering (DIS) of leptons from nuclear targets ranging from protons to heavy ions. Addressing the question on the properties of strongly interacting matter also requires the use of spin-polarized beams and/or targets at the highest energies.

Fixed target and collider experiments have contributed to the experimental attack on these questions over time. Taking beam energies of 1 GeV or greater, one has:

- fixed target heavy ion experiments (CERN-SPS, in the future at SIS-FAIR/GSI);
- fixed target proton-nucleus studies (Fermilab, J-PARC);
- heavy ion collider experiments (BNL-RHIC, CERN-LHC and in the future NICA);
- fixed target lepton DIS experiments (CERN, JLab-CEBAF);
- DIS collider experiments (formerly at DESY-HERA – in the future possibly at BNL-eRHIC, CERN-LHeC, or JLab-MEIC);
- polarized beams (RHIC, future possibilities at eRHIC and MEIC).

Recent results in this field have primarily come from RHIC at BNL and LHC at CERN. The experiments at RHIC have produced many new and often unexpected results in the first 13 years of operation. These results can be summarized as follows:

At nucleon-nucleon center of mass energy $\sqrt{s_{NN}} = 200$ GeV, central collisions of heavy nuclei produce a system that reaches a temperature of approximately 300 MeV (~4×1012 K) and very small baryon chemical potential. This temperature is well in excess of the critical transition temperature predicted by lattice gauge simulations ($T_{\text{crit}} \sim 160$ MeV). A new state of matter is produced under these conditions and observed to have the following properties:

- The matter is an almost “perfect” liquid of quarks and gluons with a shear viscosity-to-entropy density ratio near the quantum limit. This is deduced from the systematics of the collective flow imprinted on the emitted particles, which is well described by
nearly inviscid hydrodynamics. Valence quark scaling of the flow indicates that the matter is initially composed of individual quarks, not hadrons. This leads to the conclusion that the produced hot matter is a strongly coupled Quark-Gluon Plasma (sQGP).

- The matter is opaque to strongly interacting particles (deduced from “jet quenching” measurements).
- The matter is transparent to real and virtual photons (deduced from direct photon and lepton pair measurements).
- The production of heavy quarkonium states is strongly suppressed, consistent with partial screening of the color force between heavy quark-antiquark pairs inside the hot matter.
- Rapidity distributions of produced particles and the suppression of correlated particle production at forward angles in collisions of nucleons with heavy ions are consistent with the existence of a universal soft gluon component in nuclei called a Color Glass Condensate (CGC).

These observations have been confirmed measurements at almost 15 times higher center-of-mass energy at the LHC, where some heavy quarkonium states, e.g. $J/\psi$, are less strongly suppressed, probably due to final state recombination of charm quarks and antiquarks.

New questions about the properties of the sQGP have emerged from these discoveries:

1. How close is the shear viscosity-to-entropy density to the quantum bound and how does its value change with temperature?
2. How does the sQGP relate to other strongly coupled fluids, e.g., ultra-cold gases of trapped fermionic atoms?
3. Are there quasi-particles in the sQGP that survive at $T > T_{\text{crit}}$?
4. What is the color screening length in the sQGP?
5. What are the dominant parton energy-loss mechanisms in sQGP?
6. Is there a critical point in the QCD phase diagram?
7. Is chiral symmetry restored at $T > T_{\text{crit}}$?
8. How small can a droplet of sQGP be and behave collectively as “matter”?

These and many other questions are under active experimental investigation. Ongoing measurements include: the study of jets and $\gamma$-jet correlations, heavy quarks and quarkonia, low-energy beam scans and ion-nucleon collisions.

A luminosity upgrade for low beam energies using electron cooling will extend the reach of that facility into the baryon dense region of the QCD phase diagram where there are indications that the critical point may be located. Detector upgrades improving micro-vertex capabilities and calorimetry will facilitate precise heavy quark and reconstructed jet measurements.

The CERN-LHC heavy ion program will continue with up to twice higher collision energy and will study the properties of strongly interacting matter at even higher initial temperature. Heavy ion-proton collisions at the LHC can probe gluon distributions in nuclei at extremely small Bjorken-$x$ values ($x \sim 10^{-5}$) where saturation effects from the CGC are predicted to be large. Another focus of the experiments at the LHC will be hard processes, such as jets, heavy quarks and quarkonia. These processes, which are produced at the early stages of the collision, are sensitive probes of the collision dynamics at both short and long time scales.
In the next decade complementary studies of the structure of strongly interacting matter are planned at the Facility for Antiproton and Ion Research (GSI-FAIR), where fixed-target ion-ion collisions at lower energies can create nucleus-sized volumes of lower temperature, high baryon density samples of nuclear matter.

Much of our present understanding of the spin structure of strongly interacting matter comes from deep-inelastic scattering measurements of leptons on fixed targets. However, polarized hadron-hadron collisions are directly sensitive to the gluons and over the last several years significant progress has been made in understanding the role of gluons in the proton’s spin. Spin asymmetry measurements of W boson production in polarized proton-proton collisions at $\sqrt{s} = 500$ GeV at RHIC can provide flavor-separated quark and antiquark helicity distributions. Results for gluon and sea quark contributions to the proton spin from a high statistics run in 2013 are expected soon.

At high energy, two fundamental aspects of the nucleon partonic structure will remain a focus: One is the nature of the nucleon spin; the other is the nature of the quark and gluon momentum and spatial distributions in the nucleon. There are plans at BNL and Jefferson Lab to open up a new window on deep inelastic lepton-hadron experiments using electron-ion collisions. At BNL this would involve the addition of a new electron ring and new or upgraded detectors to one of the existing hadron rings. At Jefferson Lab there are plans to add a figure-eight shaped hadron ring to the existing electron accelerator. Both plans would make use of superconducting RF and energy recovery linac technology. Both proposals would make available electron-ion and polarized electron-polarized proton collisions and enable studies of the low-x structure of strongly interacting states of matter using precision (lepton) probes in novel kinematic domains.

Consideration has also being given to adding an electron ring (LHeC) to the CERN-LHC in order to study electron-nucleus collisions at extremely small values of Bjorken-x and high luminosity. Projects for possible electron-ion colliders at lower center-of-mass energy have been discussed at GSI-FAIR and in China (Lanzhou).
With the recent discovery at the LHC of a particle whose properties are fully consistent with those of the Standard Model (SM) Higgs boson, we are about to close a chapter in our quest to understand the fundamentals of the observable universe. The SM, the theory for the strong, electromagnetic (EM) and weak interactions, has to be seen as an overwhelming success, and is in remarkable agreement with the available experimental data (some anomalies aside).

While the details of the SM, such as its particle content and the values of its parameters, are rather ad hoc, its basic structure is dictated by the axioms of quantum mechanics and Lorentz invariance (the independence of physical observables from space rotations and boost transformations) implying an effective field theory (EFT) picture including an ordering principle in terms of mass scales. The fundamental SM Lagrangian arises here as the most general possibility consistent with the assumed SM particles and gauge interactions, and — most importantly — predicts fundamental symmetries such as baryon number (B) and lepton number (L) conservation to leading “renormalizable” order, i.e. up to order four in mass dimension. Various other symmetries are not exact at this level, but their violations are strongly suppressed or are otherwise known to be very small. Thus, high precision tests of fundamental symmetries in particle, nuclear, hadronic and atomic physics serve as indispensable alternatives to the energy frontier, often probing scales not accessible at any existing or planned high-energy collider.

The EFT picture fails dramatically in two respects. The cosmological constant (the unique dimension zero term and possibly the source of the “dark energy” responsible for the accelerated expansion of the universe), and likewise the bilinear (dimension two) Higgs mass term, introduce hierarchies of scales (relative to the Planck scale) which are not understood and moreover are unstable under radiative corrections. It is well possible that at least the problem related to the Higgs may be solved by the discovery of new physics beyond the SM (BSM) with a characteristic scale around a TeV. In this context it is interesting to note that the matter as described within the SM only amounts to 5% of what constitutes the universe. The “dark matter” (about 27%) is possibly a manifestation of TeV scale BSM physics, but may also be associated with very different energy scales. Nuclear physics experiments provide a special quantum context in which selection rules can be used to extract specific components of the new physics with enhanced symmetry violation effects.

For example, one can use the fact that the EM interaction is invariant under space reflections, i.e., under parity transformations (P). With the exception of the tiny $\theta_{\text{QCD}}$-term, the gauge theory for the strong interaction (QCD) also respects P, so that experiments measuring parity violating (PV) effects in atomic physics or in polarized electron scattering directly probe the weak interaction and new physics. Note, that one generally expects the latter to be chiral and therefore P violating, since this would shield new fermions from receiving ultra-heavy masses, in much the same way as the SM fermions are massless before electroweak (EW) symmetry breaking (at $\Lambda_{\text{EW}} = 246$ GeV). This strategy is particularly fruitful whenever the SM contribution to a given PV observable is small, which is the case for the left-right polarization asymmetry in both Møller (E158 at SLAC and MOLLER at Jefferson Lab) and ep scattering (Qweak at Jefferson Lab and P2 in Mainz). These experiments will determine
the weak charges \((Q_W)\) of the electron and the proton, respectively, and will not only probe multi-TeV energies, but also test the scale \((\mu)\) dependence (“running”) of the central EW gauge parameter, the weak mixing angle, \(\sin^2 \theta_W\) (see Figure 1).

**Figure 1 Calculated “running” of the weak mixing angle in the SM, as defined in the modified minimal subtraction scheme.** The theoretical uncertainty is given by the thickness of the blue curve. Red points with error bars show existing data from atomic parity violation, \(Q_W(Cs)\), SLAC-E158, NuTeV deep inelastic \(\nu\) scattering, and Z-pole asymmetries from LEP, the SLC, the Tevatron and the LHC. Green and pink points (with arbitrarily chosen ordinates) refer to ongoing and future measurements, including a plan to measure the weak charge of Ra in a single trapped ion experiment at KVI and a Jefferson Lab program in PV deep inelastic scattering. Another possibility (not shown in the figure) is to map out the sub-Z pole region to about % precision at an electron-ion collider (EIC).

This class of experiments can also constrain the properties of a dark photon which has been hypothesized as the mediator between a dark sector (possibly responsible for the dark matter) and our visible world. Interestingly, such an object could also affect the anomalous magnetic moment of the muon, \(\mu-2\), which is known to deviate at the level of three standard deviations from the SM. Thus, it is of utmost importance to improve the experimental precision in \(\mu-2\), and to reduce the theoretical (hadronic) uncertainties in its SM prediction.

One may also look for new Lorentz structures which are absent in the SM at leading order. The charged current weak interaction takes the form of a specific combination of vector and axial-vector \((V-A)\) terms (as tested in many \(\beta\)-decay experiments) and hence exhibits
maximal PV. However, the present set of experimental data cannot exclude the presence of scalar, pseudoscalar, tensor or V+A terms at the few percent level. It is then one of the goals of the program of testing fundamental symmetries to tighten these constraints on the Lorentz structure of the weak interaction through semi-leptonic decays (nuclear decay distributions) and purely leptonic decays of muons (such as by the TWIST Collaboration) and taus. Related approaches attempt to test lepton universality to very high precision in decays such as \( p \rightarrow l \nu (\gamma) \) with \( l = e \) or \( \mu \) (at PSI and TRIUMF) or to study the predicted unitarity of the CKM matrix (see below).

Much higher energy scales can be probed by electric dipole moments (EDMs). They violate time reversal invariance (T) which in any quantum field theory (QFT) is equivalent to CP invariance — the product of charge conjugation (C) and P. The observed CP violation (CPV) in K and B-meson systems is fully accounted for by the complex phase (\( \delta_{\text{CKM}} \)) appearing in the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix connecting the mass and interaction eigenstates of quarks. However, \( \delta_{\text{CKM}} \) cannot induce effects in EDMs that would be large enough to be detected in any current or planned experiment. As a consequence, if a permanent EDM was observed it would be tantamount to the discovery of a BSM effect with very far reaching consequences. To understand the deeper origin of the effect it would then be necessary to experimentally probe EDMs in as many systems as possible, including leptons, nucleons, nuclei, diamagnetic and paramagnetic atoms, and molecules. Since the \( \theta_{\text{QCD}} \)-term could induce a nucleon EDM, it would be particularly interesting to isolate a leptonic EDM. The current limit for the electron EDM, \( d_e \), can be expressed as \( |d_e| < e \Lambda_{\text{EW}} (76 \text{ PeV})^{-2} \) (with \( e \) the fundamental electric charge) which sets the sensitivity scale. The search for new sources of CPV should be a priority in that the observed baryon-antibaryon asymmetry in the universe (BAU) can only be explained by CPV beyond \( \delta_{\text{CKM}} \), and also since most BSM scenarios introduce many new complex CPV phases.

Such enormous scales can also be reached in charged lepton flavor violation (CLFV) experiments, including \( \mu^+ \rightarrow e^+ \gamma, \mu^+ \rightarrow e^- \mu^+ e^+ \), KL \( \rightarrow \mu^\pm e^- + \mu^\pm \) muonium-antimuonium oscillations and \( \mu \) to \( e \) conversion. The complementarity of these processes in the context of different BSM scenarios is well appreciated. Furthermore, the strong suppression of flavor-changing neutral currents in the SM allows for comparable sensitivities in decays such as \( K \rightarrow p \nu \nu^- \). Future measurements of the charged (CERN) and neutral (KEK and J-PARC) modes will also provide unique constraints on the smaller elements of the CKM matrix.

The BAU also calls B conservation into question. Proton decay experiments already ruled out simple scenarios of Grand Unified Theories of the strong and EW interactions probing scales in the vicinity of the fundamental Planck scale. The Planck scale itself may come into play should the QFT framework break down, signaled, e.g., by a violation of CPT invariance. The most sensitive tests look for differences in the masses or lifetimes of particles and antiparticles or compare the atomic spectra of hydrogen with antihydrogen.

Neutrino mass and mixing are now believed to be at least the major contributor to the phenomenon causing neutrinos to oscillate between flavor eigenstates as observed for solar neutrinos, atmospheric neutrinos, reactor antineutrinos, and accelerator neutrinos. The corresponding Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix is completely analogous to the CKM matrix, except that it allows for two additional complex CPV “Majorana” phases provided the neutrinos are Majorana particles (their own antiparticles). One can incorporate Majorana \( \nu \) masses within the SM (without introducing new particles) but only if one includes dimension five terms into the EFT of the SM. In this picture, the \( \nu \) mass scale of order 100 meV or less would be generated by a very large “see-saw scale” roughly of order
1014 GeV. Majorana mass terms violate L conservation and would generate \( \nu \)-less double \( \beta \)-decay. This would be a fundamental and new kind of process, and would also determine the absolute \( \nu \) mass scale (provided that the transition nuclear matrix elements can be evaluated with sufficient accuracy), while \( \nu \) oscillations are only sensitive to mass-square differences. On the other hand, should L be a fundamental symmetry of nature one would need to introduce right-handed neutrinos to allow for Dirac masses just as for quarks (but with tiny Yukawa couplings). It is stressed that with the recent extraction of the smallest of the three mixing angles (\( \theta_{13} \)) the reactor experiments Double Chooz and Daya Bay have completed the determination of the mixing part of the PMNS matrix. Moreover, \( \theta_{13} \) is large enough that one can hope to discover a non-zero value of the CPV Dirac phase (the PMNS analog to \( \delta_{\text{CKM}} \)) by studying the difference between neutrino and the corresponding antineutrino oscillations in experiments based on long baselines. It remains unknown whether the \( \nu \) spectrum is normal or inverted, i.e., whether the lightest mass eigenstate has the greatest or smallest overlap with the electron neutrino, or whether the spectrum is quasi-degenerate (insight may be gained from experiments studying neutrinos traversing the Earth to isolate matter effects). Finally, some experimental anomalies may be interpreted in terms of “sterile” \( \nu \) states (extra gauge neutral fermions) calling for further experimental efforts to clarify our understanding.
We live in a world that originated from many billions years of nuclear reactions in the cosmos. Today, our planet is energized by the nuclear fusion energy from the sun and is heated by the radioactive decay of naturally occurring materials in the earth's core. Our society relies on nuclear technologies to provide energy for our homes, diagnose and treat disease and help assure our safety and security. Accelerators that were developed initially to study nuclear reactions have played a key role in the technology revolution that has swept through much of our world in the past few decades. As our curiosity leads us to the deeper understanding of nature described in the last four sections, we gain greater ability to help solve the issues facing the world today. In the early stages of discovery, it can be difficult to appreciate how useful basic research may become. As the 2006 Physics Nobel Laureate, Dr. George Smoot, once said "People cannot foresee the future well enough to predict what's going to develop from basic research. If we only did applied research, we would still be making better spears." At the same time, it is easy to point to case histories of the tremendous impact of nuclear research and to understand the general themes where new knowledge and techniques are needed.

Perhaps the nuclear processes most familiar to the average citizen in technologically advanced regions are radiopharmaceuticals for diagnostic and therapeutic purposes. Imaging procedures rely on the penetrating nature of nuclear radiation or characteristic nuclear responses to other probes to peer revealingly inside the human body. Two commonly used examples are:

- Technetium-99m, the most common radioisotope used in medicine, is used for diagnosing medical problems in several organs, including heart, lungs, kidneys, liver and bone, among other applications in biomedical research. A recent major disruption in the global supply of Technetium-99m sent ripples throughout the medical community and has led to research to diversify the way the isotope is produced.

- 2-deoxy-2-[18F]fluoro-D-glucose (18FDG), a sugar molecule labeled with F-18, a short-lived positron emitting isotope of fluorine, has become the most widely used radiotracer for positron emission tomography (PET) imaging worldwide. 18FDG grew from a research tool to being commercially available from regional cyclotron-radiopharmacies supplying 18FDG to thousands of hospitals daily worldwide for cancer diagnosis and other nuclear medicine applications.
Other technologies such as magnetic resonance imaging (MRI), which relies on the properties of the nucleus in a magnetic field, or Computer-Assisted Tomography (CT) provide high-resolution spatial imaging. PET on the other hand detects changes in cellular metabolism (how active a cell is), often indicating the presence of disease. Combining PET's ability to show a lesion's level of cellular activity and MRI/CT's ability to show a lesion's detailed structure and location has created a new very powerful diagnostic cancer imaging tool. Together, PET/CT can be very helpful, for example, in the preoperative staging of some cancer types and in localizing suspected cancer recurrence when standard tests are inconclusive. This type of information can help physicians improve treatment planning for individual patients.

The dramatic advances in the detailed understanding of the molecular basis for many diseases offer the opportunity to design targeted functional imaging agents. This will revolutionize the specificity/selectivity of disease diagnosis and aid in the direction of therapeutic interventions.

The relatively high energy of nuclear radiation gives it the power to destroy cancerous cells. It is of most benefit to exploit this power when bio-chemical or physical mechanisms concentrate the delivery of the radiation to a specific location. Well known examples are:

- Iodine-131 which concentrates in the thyroid gland and has long been used for thyroid treatment.
- Iodine-125 and Pd-103 for seed brachytherapy for prostate and other cancers.

A compelling new technique being developed is to use two isotopes of the same element to ensure the bio-chemical distribution of the radiation is the same. One isotope provides imaging and dosimetry, for example through PET, to accurately determine where a radiation dose will be delivered and the second provides the therapeutic dose. Promising isotope pair combinations include copper-64/Cu-67, yttreium-86/Y-90, and iodine-124/I-131.

Nuclear medicine provides technological challenges that rely on progress in state-of-the-art nuclear research. One challenge is to find reliable and cost-effective means to produce and separate isotopes. This demands advances in accelerator and reactor technology and nuclear chemistry. At the research stage, often only specialized research facilities can produce limited quantities of some of the more exotic isotopes of interest. But when a treatment has proven efficacious, the demand increases many-fold. Nuclear medicine also relies on the advances in detector technology to provide new functionality, increase the resolution, or decrease the required dose that is delivered to a patient.

Direct particle-beam therapy has grown rapidly in the past decade with 30 proton and five carbon-ion beam facilities world-wide. Many new centers are in the construction or active planning stages. These therapies rely on the physical process that ions stopping in matter deposit most of their energy near their final stopping point. By precisely controlling the ion beam energy and position, a physician can optimize the dose delivered to a tumor while
minimizing dose to surrounding tissue. Impressive results have been achieved in a wide variety of cancers including salivary gland cancer, liver cancer, rectal cancer, and prostate cancer. Much of the pioneering work in this area was done at accelerators whose primary function was basic nuclear research. Today, advances in accelerator technology can improve the flexibility, accuracy, and reliability of delivery and lower the cost.

It is perhaps not widely appreciated how ubiquitous nuclear accelerators are in today’s technology. About ten thousand accelerators are in use world-wide for ion implantation to dope semiconductor chips, providing one of the bases of the rapid advances in computers and digital electronics. Approximately 1700 high current electron accelerators are producing tens of billions of dollars of value added products by cross linking polymers. These products range from the shrink wrap that protects our food to the tires on our automobiles.

The ability to peer inside matter has equal value for industry and other areas of research. Neutrons, alpha particles and gamma-rays are widely used in the oil industry to characterize the mineralogy in bore holes or in planetary probes to characterize the mineralogy of the surface of Mars. The nuclear magnetism of implanted ions can reveal the magnetic properties of thin films and material interfaces in the search for improved electronic devices. At the largest scales, the massive detectors created to determine the fundamental properties of the ghostly neutrino are now exploring the composition of the earth’s core and eagerly awaiting the next detection of the universe’s most prolific source of neutrinos, supernova explosions.

Global energy demand is projected to approximately double in the next quarter century. At the same time, serious concerns are being raised about the impact on the planet's climate of carbon-based energy sources. Nuclear energy is a reliable and greenhouse-gas free technology. In France almost 80% of electrical power comes from nuclear energy allowing it to be the world's largest exporter of electric power and with electricity costs among the lowest in Europe. Today the challenges continue to develop technologies that can improve the reliability and sustain the safety of current reactors and to develop sustainable fuel cycles while understanding and minimizing the risks of nuclear proliferation, terrorism and waste disposal.

Power reactors today are based on the fission of the isotope uranium-235. Supercomputer modeling is changing the face of reactor design, allowing scientists and engineers to explore ever-broadening options for new fuel cycles. This has placed stringent requirements for new
and often extremely high precision measurements of nuclear properties. For example, better than 1% determinations of selected probabilities of neutrons interacting with certain elements are required to optimize the performance of reactor technology options, including gas-cooled fast reactors, sodium-cooled fast reactors, lead-cooled fast reactors and extended burn-up pressurized water reactors. New fuel cycles also involve both heavy element and fission fragment isotopes that have not been studied extensively. To meet these challenges, state-of-the-art detection systems are now being developed by nuclear researchers. A fission time projection chamber is one promising avenue to achieve these new levels of precision. Accelerator mass spectroscopy has demonstrated measurements of important trace heavy elements at the parts per 10 billion levels. Techniques that were developed to study reactions on unstable nuclei in stars, so-called surrogate reactions, are being applied to deduce neutron-induced cross sections on short-lived isotopes.

Nuclear energy requires a solution for nuclear waste. Nearly all issues related to the risks to future generations arising from long-term disposal of spent nuclear fuel are primarily attributable to the transuranic elements and long-lived fission products. One approach to this problem is to use an accelerator to transmute the major intermediate-lived heavy element, americium. If one separates the energy-rich component of the spent fuel for future burn-up, accelerator transmutation can decrease the activity requiring long-term storage thereby reducing the volume, toxicity and heat generated. At the same time accelerator driven systems coupling an accelerator-neutron source with a sub-critical reactor core provide an attractive alternative to other reactor technologies. A thorium-based fuel cycle uses a fuel that is more abundant than uranium This fuel cannot support a self-sustaining chain reaction and may provide, from the beginning, an opportunity to produce much less of the minor heavy elements that pose a problem for waste disposal. The Multipurpose hYbrid Research Reactor for High-end Application (MYRRHA), an international project for an accelerator-based system to demonstrate transmutation of nuclear spent fuel, has begun at the Belgium Nuclear Research Centre. This facility will also serve as a test-bed for reactor materials and a potent source of medical isotopes.

Isotopic analysis has proven to be the ultimate nuclear detective, providing the age and often the history of small samples of matter. Today we use these techniques for radioactive dating to learn about the lifestyle of a neolithic man, the collapse of primitive societies, the flow of ocean and wind currents and the path of water deep underground. Stable isotopes tell us the history of the cosmic experiences of meteorites, the dynamics of metabolism and fingerprint the paint of famous artists. Nuclear techniques have evolved from low-level counting and standard mass spectrometry to accelerator mass spectroscopy and most recently atom-trap trace analysis that can measure at the parts per million-billion level. One example of a global problem under study is the decreasing availability of fresh water. An International Atomic Energy Agency project is mapping the ground water resources of the world using isotopic
Reducing the proliferation of nuclear weapons is an important goal throughout the world. While this is a many-faceted subject, there are three aspects of this topic that emphasize the importance of progress in nuclear physics. The current prohibition on nuclear testing is one component. But without testing, major nuclear powers must rely on a scientific program to increase their understanding and thus certify existing nuclear stockpiles. Nuclear science contributes to this enterprise through the measurement and calculation of certain reaction rates and the development of diagnostic techniques that are needed to evaluate the simulations of weapon performance. The second aspect is monitoring existing nuclear materials and seeking out illicit smuggling of potential weapons grade material and technology. Nuclear scientists are developing detectors to detect the movement of nuclear material and to monitor ports and border crossings. Advanced technologies are being developed for both accelerator-based and cosmic-ray-background-based detection. A third aspect is a push to find alternative technologies such as accelerator driven systems to replace high-enrichment uranium use in reactors or as targets for isotope production. Such alternative technologies can significantly reduce the need to transport uranium in a form that could be diverted to create weapons.

These are just some of the examples of technology evolving from basic nuclear research serving society. Others range from the nuclear power generators in robotic missions to explore other planets to the emergency exit signs in airplanes or the smoke detectors in our dwellings. All point to the value we have gained from mastering the secrets of the nucleus and the need for the highly trained workforce that can continue to advance the knowledge, techniques and tools of nuclear science to apply them to the challenges of our world, new and old.
The most prominent task of IUPAP WG.9 is to sketch a framework for the key issues in nuclear science research for the next 10 to 20 years. In the following an overview is given of the current and future nuclear physics facilities worldwide.

Up to the recent past experimental nuclear physics has advanced based on firm international competition and collaborations. However, as of to date nuclear physics research has advanced to a stage that requires the construction of facilities often beyond the capacity of a single nation. The price tag for an international user facility may not be as large as projected for the International Linear Collider (ILC) in its Technical Design Report of June 12, 2013, but the sum of the costs for the running of all the presently existing and construction of the proposed nuclear-physics facilities worldwide is reaching the level of construction of the ILC. This also implies that there soon will be not only budgetary limitations but also human resources shortages to launch a future large-scale nuclear physics facility. Clearly this fact needs to be recognized and efforts made to enhance worldwide cooperation while keeping a good balance between domestic, regional (Europe-Africa, Asia-Oceania, and North-South America), and truly international projects.

Table 1 summarizes the subfields of nuclear physics and the main topics to be covered. All the subfields contain the most prominent scientific topics. Here the focus is on the facilities which carry out experiments in the first three subfields, namely, “Hot QCD”, “Cold QCD”, and Nuclear Structure Physics. The latter category requires radioactive (or rare) isotope (RI) beams either from an ISOL (Isotope Separation On-Line) facility or an in-flight projectile fragmentation facility with heavy-ion beams.

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<th>Subfield</th>
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<td>Quark many body -Hot QCD-</td>
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<td>-properties of the early universe-</td>
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<tr>
<td>Application</td>
<td>Nuclear Transformation, Catalyzed Fusion, etc.</td>
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*Table 1. Subfields of Nuclear Physics.*
Table 2 gives the list of the large-scale facilities that recently have come into operation, are under construction at the present, or are being proposed, in each geographical region. One notices that on the American continent, the projects are well distributed probably due to the control exerted by the US government. The mechanism working on the American continent is a two-body interaction, with Canada cleverly covering the subfields not covered by the US. Europeans are trying a kind of role-sharing by proposing EURISOL. In Asia, there is no such co-operation. Every nation is advancing its own research interests under the (weekly coupled) three nation entity made up by China, Korea and Japan. The recent establishment of ANPhA (Asia Nuclear Physics Association) may be a key to improve the present situation of collaborations in Asia. IUPAP WG9 may then be responsible for furthering applicable worldwide co-operations.

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<th>Subfield</th>
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<td>FAIR(SIS300)</td>
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<td>Quark many body -Cold QCD-</td>
<td>hadron beams</td>
<td>CERN SPS</td>
<td>J-PARC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FAIR(SIS100)</td>
<td>HIRFL</td>
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<tr>
<td></td>
<td>lepton beams</td>
<td>JLAB(12GeV)</td>
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<td>Spring-8</td>
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<tr>
<td></td>
<td></td>
<td>elC(e-A)</td>
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<tr>
<td></td>
<td></td>
<td>NICA(A-A/p-p)</td>
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<tr>
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<td>Projectile Fragmentation RI beams</td>
<td>FRIB</td>
<td>FAIR</td>
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<tr>
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<td>ISOL RI beams</td>
<td>ARIEL/ISAC2</td>
<td>SPIRAL2</td>
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<td></td>
<td></td>
<td>SPES</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HIE-ISOLDE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HIRFL BRIF2</td>
</tr>
<tr>
<td>Super ISOL</td>
<td>FRIB upgrade</td>
<td>EURISOL</td>
<td>CARIF</td>
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Table 2. List of large-scale nuclear physics facilities. The bold characters are for the running facilities, italics for those under construction, and the gray cells for proposed facilities.

Hot QCD: This subfield actually started in the late seventies at LBL in the US. In the mid-eighties relativistic heavy-ion programs emerged at the SPS of CERN and the AGS of BNL. Until the very end of the SPS heavy-ion physics program, it was not clear whether the conditions of the Quark Gluon Plasma (QGP) had been reached.

RHIC started operations in 2000 and finally the discovery of a new state of matter (QGP) could be announced. The ALICE experiment at the CERN-LHC started in 2010 and re-discovered this new state of matter. After 30 years of research convincing arguments finally exist regarding the existence of this new state of matter. Both colliders have another 10-15 years of productive research in studying the properties of QGP. It may then very well be that the relativistic heavy-ion colliders are replaced by electron-ion colliders (elC’s). A white paper for such a facility is being presented to the US government. At CERN there are discussions about a high energy electron-ion collider (LHeC Project).

The history of the “Hot QCD” research has been quite successful not only by reaching in the phase diagram the conditions leading to QGP but also by the healthy growth of international collaborations; researchers got together at accelerators at which one nation alone could not sustain the heavy-ion research program. However, it should be remembered, that none of the facilities for the QGP studies was built from “a green field” by the nuclear physics community (i.e., they were realized by converting an existing accelerator or using an existing tunnel to construct a heavy-ion collider).
What comprises “Dense QCD” is studied at lower-energy heavy-ion colliders, of which FAIR (Facility for Antiproton and Ion Research) at GSI is under construction and NICA (Nuclotron based Ion Collider fAcility) at JINR is being proposed.

FAIR will come on line in a few years. This will be the leading European nuclear physics facility covering “Hot QCD”, “Cold QCD”, and for in-flight projectile fragmentation produced RI beams. FAIR’s accelerator complex is very versatile and ingenious; SIS-300 for “Hot/Dense QCD”, SIS-100 for “Cold QCD”, and RI beams by projectile fragmentation. The physics program is well thought out, with an emphasis on those experiments where other facilities cannot compete; consequently no neutrino physics experiments, no hyper-nucleus physics experiments. This versatility is not made possible for free. Many different types of rings must be built, which is a rather complex enterprise.

NICA could be considered as a smaller version of RHIC: nucleus-nucleus and polarized proton-proton and polarized proton-nucleus collisions at lower energies. Like FAIR, a new area of high density QCD with A+A collisions will be probed. The energy region, however, was once searched by the SPS heavy-ion project. It will be a challenge to repeat making new discoveries like at RHIC and LHC.

Cold QCD: Until FAIR becomes operational, J-PARC’s 30 GeV Proton Synchrotron in Japan will continue to be the world leading facility for “Cold QCD” physics using hadron beams. For the moment, there are only two beam lines for low momentum kaons and one neutral kaon beam line for the K0 -> p0-n-n experiment. With last year’s supplementary funds for two new beam lines, experiments to study hadron mass modifications in the nuclear environment can be mounted and a muon-electron conversion experiment can be initiated. J-PARC’s current proton beam power of 10-20 kW (slow extraction), is surely to reach 100kW by 2015. An extension of the experimental hall to 2.5 times the current size has been proposed.

Amongst a handful of lepton-photon beam facilities in the world, Jefferson Laboratory (JLab) in the USA is playing the leading role. The CEBAF energy upgrade from 6 GeV to 12 GeV is about to be completed. Included in the upgrade project is a new experimental Hall D for a Bremsstrahlung-photon beam with a new 4p detector. The CLAS spectrometer in Hall B will also be upgraded. JLab ranks prominently in performing electron scattering parity violation experiments to test the Standard Model.

The world’s first electron Ion Collider (eIC) is proposed to be built either at BNL by adding an electron ring in the RHIC tunnel or by adding two ion-cooler rings to CEBAF at JLab. The electron-proton colliding luminosity will be 100 times higher than at the former HERA collider. A new regime of QCD, the saturated gluonic field in the nucleon and nucleus will be explored. In addition, one should not forget the hadron physics capability of the B-factory where many new hadron resonances have been discovered.

Nuclear physics with ISOL beams: EURISOL is the future facility with a multi-billion-dollar price tag, carrying the aspirations of many European nuclear physicists. Twenty institutions in Europe signed on to the design report with in addition contributions from twenty other institutions from America and Asia. The Nuclear Physics European Collaboration Committee (NuPECC) has agreed that EURISOL, together with GSI/FAIR, are priority goals. Other ongoing projects such as SPIRAL2 at GANIL, HIE-ISOLDE at CERN, and SPES at INFN-Legnaro are now regarded as “intermediate” facilities. This is a very clever and honest approach that satisfies national pride as well as determines the future direction of the projects.
within the EU.

Although declared as “intermediate”, these facilities are anything but minor and are already powerful. HIE ISOLDE at CERN is a natural extension of the present facility by the addition of a 10MeV/A post-accelerator. SPES at INFN-Legnaro is a relatively modest 8kW-ISOL project. SPIRAL2 in GANIL involves building a 200kW ISOL driven by a deuteron superconducting linac which will double the scale of the present GANIL facility. A low-energy RI laboratory and a neutron laboratory are also scheduled to be built.

Table 3 summarizes the ISOL facilities under construction or being planned. While the

<table>
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<tr>
<th>Type</th>
<th>Facility</th>
<th>Beam Power (kw)</th>
<th>Direct</th>
<th>Beam pna</th>
<th>Post acceleration</th>
<th>Start</th>
</tr>
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<td>1*10^14</td>
<td>2*10^8</td>
<td>2015</td>
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<td>D&amp;C</td>
<td>4*10^12</td>
<td>5-10</td>
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<td>SPIRAL2 d 40MeV 5000mA</td>
<td>200</td>
<td>Conv</td>
<td>1*10^14</td>
<td>3-10</td>
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<td>ISOL coming</td>
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<td>8</td>
<td>Direct</td>
<td>1*10^13</td>
<td>10</td>
<td>3*10^4</td>
</tr>
<tr>
<td>Super ISOL</td>
<td>EUR ISOL p 1GeV 5000 mA</td>
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<td>5*10^10</td>
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<td>8300 pna</td>
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<td>400</td>
<td>PF</td>
<td>8000 pna</td>
<td>-</td>
<td>10^9-10^10</td>
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<td>FAIR U+28 1500MeV</td>
<td>10</td>
<td>PF</td>
<td>50 pna</td>
<td>-</td>
<td>10^7-10^8</td>
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<tr>
<td>PF running</td>
<td>RIBF 2015 U+86 345MeV</td>
<td>4</td>
<td>PF</td>
<td>100 pna</td>
<td>-</td>
<td>3*10^6</td>
</tr>
</tbody>
</table>

Table 3. Brief comparison of the future large-scale RI-beam facilities. Start dates are quoted from the original plan; and are subject to be updated. PF stands for projectile fragmentation.

existing facilities provide 1011-1012 fissions/s with a typical 132Sn intensity of 106, the European “intermediate” facilities provide 1012-1014 fissions/s with 132Sn of 108-109. In Canada, ARIEL at TRIUMF is under construction which aims at 1014 fission/s with the use of a superconducting electron linac developed in conjunction with the ILC R&D program. These facilities under construction will provide typically 100 times more RI compared to current levels. For the far future, EURISOL aims at 1016 fissions/s driven by 1GeV protons of 4MW beam power. In Asia China is considering to build CARIF (China Advanced Rare Ion-beam Facility, now called Beijing ISOL) driven by an existing research reactor. Despite the difference in their drivers, the performance of CARIF is expected to be comparable to EURISOL, i.e., ~100 times more intense than the soon-to-be-ready ISOL facilities.
mentioned. Although there is no regional consensus in Asia, CARIF can be called AsianiSOL (ASOL). Until CARIF becomes operational, China will operate two facilities: BRIF (Beijing RI Facility) which will be upgraded to BRIF2 in 2014, and Heavy Ion Research Facility in Lanzhou (HIRFL). The Institute for Modern Physics in Lanzhou has plans to build a higher intensity accelerator HIAF in the next 10 years. It should be noted RIKEN RIBF today can deliver 200 MeV/A 132Sn with 3*10^5 regularly, and with 3*10^6 by 2015.

RI beam with projectile fragmentation: Table 3 also includes the RI-beam facilities with projectile fragmentation. Compared to the ISOL facilities, the projectile fragmentation facilities are superior in producing a wide range of rare RI beams, free from their chemical characteristics and short lifetime. Among these facilities, RIBF at RIKEN currently delivers the most powerful RI beams. Koreans have come up with the RISP project to be launched in five years. Furthermore, the FRIB project at Michigan State University, very recently approved for construction, will be completed by 2022 (partial start slated for 2020). RISP and FRIB are aiming for a similar level of performance.

FAIR at GSI is another large facility. Using SIS100 with a U28+ 1.5GeV/A beam, it can improve the RI beam intensity by a factor of 100 to 1000 compared to the present SIS-based facility, making the facility comparable or superior to RIKEN RIBF.

FRIB at MSU is truly the next generation projectile-fragmentation facility with 200MeV/A 400kW LINAC followed by a fragmentation separator. Future options are to double the energy and to add an ISOL facility. To compete with FRIB (and RISP), RIKEN RIBF needs to upgrade by replacing the first cyclotron with a super conducting linac.

* * * *

In summary, one recognizes from Table 2 that the “Hot QCD” and “Cold QCD” facilities are shared well efficiently worldwide. Compared to twenty years ago, there are fewer “Cold QCD” laboratories because they have been left for the collider projects. By having an electron-ion collider in the USA in the future, scientific coverage will be drastically expanded in parallel with more well-balanced regional interests and responsibilities. Assisted by the international competition among the rival facilities in the European, American and Asian continents, RI-beam facilities have become prevalent. Huge advances in this field of physics are to be expected in the coming 10-20 years. One may need to consider international amalgamation of research interests when either EURISOL or CARIF, both multi-billion dollar projects, is eventually realized.
Energy needs are increasing all over the world. Large quantities of additional energy will be needed to fuel economic growth, especially in developing countries with large populations like China, India and Brazil. Currently, some two billion people have no access whatsoever to commercial energy; many more are quite poor by western standards and all will need more energy in the future. Worldwide demand will continuously grow and will double by 2050.1)

The relative growth will be even larger for electricity since, more than any other form of energy, electricity is an essential ingredient of economic development. Providing more energy while at the same time limiting the use of fossil fuels is a difficult proposition. There is no simple solution. All available options must be considered with an open mind. Conservation and improved energy efficiency are the most effective options for the next few decades, but these will not be enough on their own. The rate of improvement in efficiency over the last few decades has been smaller than the rate of growth in economic activity, so that energy demand has continued to rise. For the developing world, whose population is fast growing and starts from a small economic base, economic growth is faster and, in the normal course of events, energy use will actually grow faster still for some time to come. Terabyte computers, massive data storage devices, video games, personal computers, for example, require considerable amounts of electricity. The world as a whole, therefore, needs to develop carbon-free energy sources.

Concerns about air quality, climate change and fossil fuel shortages are giving a new impulse to the development of nuclear power. China, in particular, has 17 nuclear power reactors in operation, 32 under construction. Additional reactors are planned, including some of the worlds most advanced, to give more than a tenfold increase in nuclear capacity.2)

New Energy Technologies

Renewable energy sources, e.g., hydro-power, solar power, wind power, etc., are carbon free and there is a widespread hope that they will supply higher and higher percentages of the energy mix, but it will take a long time. This is not because of insufficient research and development (R&D) of incentives. Solar photovoltaics, for instance, have benefited from large R&D investments. Similarly, wind farms are being built worldwide. The problem is the high cost of the energy generated, the absence of sufficient storage capacity for intermittent sources. One will need a new generation of smart grids and efficient grid management to inject intermittent sources of energy into the grid. Their deployment will also require to overcome the resistance to employing these low intensity sources, which inevitably impact significantly the local environment. Hydro-power is cost effective, but potential sites are limited and often precious for other reasons so that its growth is also constrained. Renewable energy sources will not, at least for the foreseeable future, provide for the increased energy needs.

Most popular at present is the increased use of natural gas.3) New technologies have allowed to significantly increase the extraction of natural gas from unconventional gas reservoirs. These unconventional gas reservoirs represent a vast, medium-term, global source of natural gas, which have not yet been fully appraised. Unconventional gas resources — including tar sands, coal bed methane, and shale gas constitute some of the largest components of remaining natural gas resources in the United States. The OECD expects gas to supply a larger share of the larger energy demand that is expected in the future. Although it is a fossil fuel and does produce CO2 gas as waste, it is cleaner than oil or coal and can be used more
efficiently in many applications. It is today relatively cheap, but there are concerns that this will not remain so as demand grows and increasingly higher-cost supplies must be brought on-line.

**Fig. 1. Change in power generation 2010 – 2035, ref. 1)**

**Nuclear Power**

Generation I reactors were developed in the 1950-60’s. Generation II reactors are in operation all over the world. Generation III is the new generation of advanced reactors that are being built. The first of these are in operation in Japan and others are under construction or about to be ordered to be built.

Generation IV designs are still on the drawing board and will not be operational before 2030. On the longer term, the "Generation IV" research initiatives aim to develop, for deployment around 2050, new types of nuclear reactors which are simpler, completely free from core-meltdown, and competitive with the best fossil-fired power plants, as well with fuel cycles more resistant to proliferation 4). Comprehensive assessment studies have demonstrated that these objectives are achievable. An agreement to develop advanced reactors in the framework of the Generation IV forum has been signed by France, Japan, and the United States.

Today, there are some 435 nuclear power reactors operating in 31 countries plus Taiwan, with a combined capacity of over 370 GWe. In 2011 these provided 2.5 TWh, about 13.5% of the world’s electricity. Nuclear power capacity worldwide is increasing steadily, with over 60 reactors under construction in 13 countries. Significant further capacity is being created by plant upgrading. Most reactors on order to be built or planned are in Asia 2).

In 2004, the use of fossil fuels appeared to be able to supply almost all of the increased energy use till 2020. Nuclear power was predicted to decline, from 17 % of electricity generation in 1995 to 9 % in 2020. Recently a new nuclear energy roadmap has been prepared jointly by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) 5). This study emphasizes that unlike most other low-carbon energy sources, nuclear energy is a mature technology that has been in use for more than 50 years. The latest designs for nuclear power plants build on this experience offer enhanced safety and performance, and are ready for a wider deployment over the next few years. Several countries are reactivating their nuclear programs, while others are considering nuclear power for the first time. In the longer term, there is great potential for new developments in nuclear energy technology to enhance the role of nuclear power for a sustainable energy future.

However, on 11 March 2011, the Fukushima Daiichi disaster 6) has had a major impact on the future perspectives for nuclear power worldwide. The Fukushima Daiichi nuclear disaster
was caused by a series of equipment failures, nuclear meltdowns and releases of radioactive materials at the Fukushima I Nuclear Power Plant, following the Tohoku earthquake and tsunami. It is the largest nuclear disaster since the Chernobyl disaster of 1986 and the second disaster (along with Chernobyl) to reach a Level 7 on the International Nuclear Event Scale. The tsunami flooded the emergency electric generators that failed, cutting power to the critical pumps that must continuously circulate coolant water through a Generation II reactor for several days to keep it from melting down after shut down. After the pumps stopped, the reactors overheated due to the normal high radioactive decay heat produced in the first few days after a nuclear reactor shutdown. Such an accident would not happen with a Generation III reactor.

The Fukushima accident investigation revealed that safety records had been falsified and many warnings, both national and international, of the possibility of flooding of the emergency pumps due to a Level 7 seismic event had been ignored. This has created great consternation in Japan and all over the world. Scientific experts have considerably helped to have a clear vision at the policy level of the realistic impact of the situation that had developed.

Industry has introduced considerable measures to take into account the lessons from Fukushima. Only Germany and Japan in first instance have decided to decommission their nuclear power reactors. It is interesting to note that in Germany this has led to a considerable increase in the use of coal as fossil fuel.

A recent OECD study, which examined a selection of OECD member countries, qualitatively and quantitatively validates the often intuitive assumption that, as a largely domestic source of electricity with stable costs and no greenhouse gas emissions during production, nuclear energy can make an important positive contribution. Following an analysis of the meaning and context of security of supply, the study using transparent and policy-relevant indicators shows that, together with improvements in energy efficiencies, nuclear energy has indeed contributed significantly to an enhanced energy supply security in the OECD countries over the past 40 years.

Globally, the processing of spent fuels, the consumption of the plutonium in light water reactors, and the transmutation of long-life radiotoxic wastes (minor actinides) in the new generation of reactors, could reduce the long-life radio-toxicity of the waste by a factor of 100, leaving a residual radioactivity that would then be comparable to that of the initial natural uranium after several hundred years. The development, in an extended international framework, of a new generation of nuclear power production systems offers attractive opportunities for meeting the challenges for the development of carbon-free sustainable energy sources. The characteristics of this technology are promising (in terms of costs, safety, environmental protection) and offer the possibility of implementing several configurations, suited to the economic and technical context in question, thereby enabling a gradual deployment on the international market.

**Nuclear wastes**

Considerable technical progress has been made over the last 10 years. Solutions do exist and could be gradually implemented, but the perception of the public remains a major obstacle to political decisions. The Blue Ribbon Committee on America’s nuclear future recognized that America’s nuclear waste management program is at an impasse.

The concept of deep geologic disposal of high level wastes has been studied extensively in many national and international research programs for several decades. Extensive research has been done in particular in France for 15 years as legislated by the French Parliament. France and Sweden have decided to dispose of nuclear wastes in a geological repository. Such a repository is believed to provide an effective and acceptable technical solution for the
long-term management of the radioactive wastes. Although practical experience in building and operating geologic repositories for high-level waste is still mainly limited to a few pilot-scale facilities, there is today a high level of confidence within the scientific and engineering community that the geologic repository approach is capable of safely isolating the waste from the biosphere for as long as it poses significant risks. This view has been stated and supported in several recent national and international assessments 6-10). These conclusions are discussed in the MIT interdisciplinary study on "The Future of Nuclear Power" 7).

Although the details vary among national programs, the basic approach to repository design in every case is based on a multi-barrier containment strategy, combining a suitable geologic, hydrologic, and geochemical environment with an engineered barrier system that takes advantage of the main features of that environment. A well-chosen geologic environment will support and enhance the functioning of the engineered barrier system, while protecting it from large perturbations such as tectonic activity or fluctuations in groundwater chemistry due to glaciation or other climate changes.

Research will explore the potential for new reactor concepts and/or fuel cycles to produce less waste during operation of nuclear power plants. Studies are underway on multiple recycling of plutonium in power reactors, thus destroying it and leaving the fission fragments and minor actinides for geological storage. Also under study are transmutation systems which convert the long-lived component of spent fuel to a form only requiring insulation for on the order of hundreds of years to a thousand years, a time span of already existing man-made structures.

**Partitioning and transmutation technology (P&T)**

P&T research is recognized as a lead to systems that would effectively reduce the volume and long-term toxicity of radioactive waste emanating either from the reprocessing of spent nuclear fuel or the spent fuel itself.

Partitioning and transmutation technology addresses some of the important concerns about nuclear waste management using future nuclear reactors. Current experimental research in Europe and Japan is focused on the evaluation of different concepts and future infrastructures requirements. The goal is to build a strong R&D community bridging academic and industry technology research.

In Japan, there is an important R&D research program on nuclear transmutation. The EU has developed major collaborative experimental programs 11, 12). MYRRHA is the most ambitious Accelerator Driven System (ADS) project in Europe. Recently, the Belgian government has decided to finance 40% of the MYRRHA project (1 Billion Euros). This project is expected to be completed in 13 to 15 years.

**Conclusions**

Nuclear energy is still perceived as a clean and economical source of energy. After Fukushima, all nations have realized the need for a new approach to safety and sustainability. Economics drive the future of nuclear energy and wastes management; most nations continue to follow their nuclear energy construction portfolios. The future of the nuclear fuel cycle is one of the most important issues.

In the United States the nuclear Industry expects a rebound. Japan needs time to find the best way to recover from the nuclear accident. The Japanese industry focuses its efforts on foreign markets. The construction of new nuclear reactors is located at the present mostly in China. The first EPR water pressure reactor built in China is expected to become operational in 2014. China employs considerable efforts to learn from existing designs and to prepare a
new generation of power reactors. Their goal is to develop purely Chinese reactors and sell these worldwide. The eastern countries (China, India, Japan, and Korea) are taking the lead.

Solutions for the management of nuclear wastes do exist, but the public opinion has yet to be convinced that these solutions are safe and reliable. The example of Sweden 13) might be one of the most convincing examples of information for the public and the organization of national debates leading to a non-controversial decision. The French Parliament has decided to dispose of the high level radioactive nuclear wastes in a geological repository after reprocessing.

Pure and Applied Research will continue to bring innovations, support industry and give confidence in future designs. Thus, nuclear power should be an important contributor to satisfy the needs of the growing energy demands of the world. This will be of great importance to fight poverty and produce sufficient energy for all.

References
2) http://www.world-nuclear.org/
3) IEA - Energy Technology Perspectives 2012.
5) Blue Ribbon Committee report 2011 on America’s nuclear future.
12) http://setis.ec.europa.eu/technologies/Nuclear-fission-power/info
Introduction

INDIVIDUAL LABORATORY ENTRIES BY GEOGRAPHICAL REGION

Nuclear Physics Institutes and Laboratories worldwide which possess an accelerator with an external users group for research in nuclear physics are indicated on the following map and listed in the following two Tables. Table I gives the names of the Nuclear Physics Laboratories, their location, and the chief performance characteristics of the laboratory's accelerator(s). Table II gives the staffing levels of the Nuclear Physics Laboratories as well as the total number of users and how these divide into internal users, national users and international users.

There are a very large number of medium size and smaller size facilities. It must be recognized that these facilities have a very important role in the education and training of nuclear physicists. In addition these facilities in general serve society at large through various applied nuclear physics programs and in quite a few cases have important programs within nuclear medicine.

If one were to make the arbitrary choice to define truly international user facilities in nuclear physics as those which have a users group of national and international users combined in excess of 300 scientists, one would identify: in Japan J-PARC, RCNP, and RIKEN, in France GANIL, in Germany DESY-HERA, GSI, and COSY, in Italy Laboratori Nazionali di Legnaro, in Switzerland CERN and PSI, in Canada TRIUMF, and in the USA, ANL, BNL, JLAB and NSCL-FRIB. Other choices are possible and in some contexts perhaps more desirable, but this small group of large facilities would appear in almost any such collection.

The individual entries on the Nuclear Physics Laboratories are primarily the responses obtained through a questionnaire that was widely circulated. In a few cases in Europe, entries were taken from the NuPECC Handbook on International Access to Nuclear Physics Facilities. As the information was provided on a purely voluntary basis, there are some unavoidable gaps. For example, we had few responses from India. In that case we list below the web pages of several key institutions from which we did not receive information. Additional information on laboratories as defined above and not yet listed would be appreciated.

Centre for Advanced Technology (Department of Atomic Energy), Indore [Synchrotron Radiation Facility, 450 MeV] www.cat.ernet.in

Bhabha Atomic Research Centre (Department of Atomic Energy), Mumbai [Research Reactors] www.barc.ernet.in

Tata Institute for Fundamental Research, Mumbai [Pelletron] www.tifri.res.in
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<th>Region / Country</th>
<th>Institution</th>
<th>Facility Name</th>
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<th>Theory (total)</th>
<th>Permanent</th>
<th>Temporary</th>
<th>Postdocs</th>
<th>PhD Students</th>
<th>Onsite / Other Graduate Students</th>
<th>Undergraduates</th>
<th>Total user number</th>
<th>Internal (%)</th>
<th>National (%)</th>
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<td>South Africa</td>
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<td>Cyclotron &amp; Accelerator Facility</td>
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<td>Chinese Academy of Sciences, SIAP, Shanghai</td>
<td>SLEGS (in planning)</td>
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<td>0/3</td>
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<td>95%</td>
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<td>Inter-University Accelerator Center</td>
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<td>20%</td>
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<td>Van de Graaff Laboratory</td>
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<td>5%</td>
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<td>Center for Proton Therapy</td>
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<td>Heavy Ion Accelerator Facility</td>
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<td>Centre de Recherche du Cyclotron</td>
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<td>Academy of Sciences of the Czech Republic, Kež</td>
<td>Nuclear Physics Institute</td>
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<td>25</td>
<td>4</td>
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<td>Facility Name</td>
<td>Staff</td>
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<td>Finland</td>
<td>University of Jyväskylä, Jyväskylä</td>
<td>Accelerator Laboratory</td>
<td>Total 68</td>
<td>Theory (total) 9</td>
<td>Permanent 26</td>
<td>Temporary 42</td>
<td>Postdocs 9</td>
<td>PhD Students 32</td>
<td>Other Graduate Students 10</td>
<td>Undergraduates 270</td>
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<td>National (%) 25%</td>
<td>International (%) 75%</td>
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<td>France</td>
<td>Centre d’Etudes Nucléaires Bordeaux Gradignan (CENBG), Gradignan</td>
<td>AIFIRA</td>
<td>Total 17</td>
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<td>Permanent 10</td>
<td>Temporary 7</td>
<td>Postdocs 3</td>
<td>PhD Students 4/0</td>
<td>Other Graduate Students 0</td>
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<td>Total user number 60</td>
<td>Internal (%) 65%</td>
<td>National (%) 95%</td>
<td>International (%) 5%</td>
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<td>CNRS, Université de Nantes, École des Mines de Nantes, Nantes</td>
<td>ARRONAX</td>
<td>Total 452</td>
<td>Theory (total) 5</td>
<td>Permanent 382</td>
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<td>PhD Students 10</td>
<td>Other Graduate Students 3</td>
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<td>Internal (%) 7%</td>
<td>National (%) 26%</td>
<td>International (%) 74%</td>
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<td>ESRF GRAAL</td>
<td>Total 35</td>
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<td>PhD Students 15/0</td>
<td>Other Graduate Students 3</td>
<td>Undergraduates 130</td>
<td>Total user number 130</td>
<td>Internal (%) 22%</td>
<td>National (%) 64%</td>
<td>International (%) 36%</td>
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<td>GANIL Laboratory, Caen</td>
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<td>Theory (total) 8</td>
<td>Permanent 242</td>
<td>Temporary 25</td>
<td>Postdocs 4</td>
<td>PhD Students 9/8</td>
<td>Other Graduate Students 20</td>
<td>Undergraduates 370</td>
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<td>National (%) 26%</td>
<td>International (%) 74%</td>
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<td>IPNL Van de Graaffs</td>
<td>Total 29</td>
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<td>Postdocs 6/1</td>
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<td>Other Graduate Students 0</td>
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<td>National (%) 95%</td>
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<td>Institut Laue-Langevin, Grenoble</td>
<td>ILL</td>
<td>Total 452</td>
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<td>Permanent 382</td>
<td>Temporary 18</td>
<td>Postdocs 20</td>
<td>PhD Students 10</td>
<td>Other Graduate Students 3</td>
<td>Undergraduates 1220</td>
<td>Total user number 1220</td>
<td>Internal (%) 7%</td>
<td>National (%) 26%</td>
<td>International (%) 74%</td>
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<td>Total 38</td>
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<td>PhD Students 10</td>
<td>Other Graduate Students 10</td>
<td>Undergraduates 130</td>
<td>Total user number 130</td>
<td>Internal (%) 22%</td>
<td>National (%) 64%</td>
<td>International (%) 36%</td>
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<td>Germany</td>
<td>Deutsches Elektronen-Synchrotron (DESY), Hamburg</td>
<td>HERA Note: Nuclear Physics about 10% of figures given</td>
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<td>Other Graduate Students 45</td>
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<td>National (%) 53%</td>
<td>International (%) 47%</td>
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<td>FRM II</td>
<td>Total 220</td>
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<td>International (%) 38%</td>
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<td>International (%) 56%</td>
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<td>Postdocs 5</td>
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<td>International (%) 25%</td>
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<td>Other Graduate Students 0</td>
<td>Undergraduates 0</td>
<td>Total user number 0</td>
<td>Internal (%) 0%</td>
<td>National (%) 0%</td>
<td>International (%) 0%</td>
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<td>Tandem Accelerator</td>
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<td>International (%) 34%</td>
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<td>Other Graduate Students 0</td>
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<td>National (%) 80%</td>
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<td>Undergraduates 0</td>
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<td>International (%) 0%</td>
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<td>Other Graduate Students 0</td>
<td>Undergraduates 0</td>
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<td>National (%) 0%</td>
<td>International (%) 0%</td>
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<td>Laboratori Nazionali del Gran Sasso</td>
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<td>Temporary 40</td>
<td>Postdocs 12</td>
<td>PhD Students 10/-</td>
<td>Other Graduate Students 6</td>
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<td>Other Graduate Students 0</td>
<td>Undergraduates 0</td>
<td>Total user number 0</td>
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<td>National (%) 0%</td>
<td>International (%) 0%</td>
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<td>Facility Name</td>
<td>Total</td>
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<td>Temporary</td>
<td>Postdoc</td>
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<td>Onsite/Other</td>
<td>Graduate Students</td>
<td>Undergraduates</td>
<td>Total User Number</td>
<td>Internal (%)</td>
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<td>Research Reactor / n(3-10Å, 10^7 s^-1 cm^-2) / 4 MV VdG: p, d, ^4He, N</td>
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<td>Cycl-Synch-Storage-R / p (3.7 GeV) / HI (1.1 GeV/u, ^4He, U 520 MeV/u)</td>
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<td>SLEG5 (in planning)</td>
<td>Gamma rays / 1-25 MeV 10^-10^10 s^-1</td>
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<td>Tandem - S.C.Linac HI (9-1 MeV/u)</td>
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<td>AVF Cyclotron K=40, 20-7 MeV/u SC-Cyclotron, K=500, 10-30 MeV/u</td>
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<td>Japan</td>
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<td>Tandem-ISOL-S.C-Linac / p(20 MeV) / HI (A=15/200 20/5 MeV/u)</td>
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<td>Synchrotron / p (30/50) GeV &gt; 10^14 s^-1</td>
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<td>Synchrotron / p(8 MV) / HI (A&lt;150, 0-300 MeV/u) / medical</td>
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<td>0.5-1.5 GeV electrons in storage ring, LC photonbeam</td>
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<td>Van de Graaff (5MV) / p-He (5 MeV/10 MeV)</td>
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<td>Cyclotrons (K140 + K400) / p (400 MeV) / HI (A&lt;20, 100 MeV/u)</td>
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<td>Cyclotrons / RARF (&lt;135 MeV/u) / RIBF (6U / 350 MeV/u)</td>
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<td>Cyclotron / p (50-230 MeV)</td>
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<td>Electrost. Ion Acc./ AMS Fac.</td>
<td>Tandem (4 MV) / p(6 MeV) / HI (14^10 C 10 MeV)</td>
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<td>Singletron(3.5 MV) / p (3.5 MeV) / n (7 MeV)</td>
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<td>Cyclotron (K=70) planned; radioisotope production and nuclear medicine</td>
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<td>ESRF GRAAL</td>
<td>Gamma Rays (Compton back-scattered polarized) (550-1500 MeV)</td>
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<td>Institut Laue-Langevin, Grenoble</td>
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<td>Research Reactor / n (10⁻²⁸ s⁻¹ cm⁻²)</td>
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<td>France</td>
<td>Institut Physique Nucléaire d'Orsay, Orsay</td>
<td>Tandem / ALTO</td>
<td>Cyclotron (K=20) / p (20 MeV) / HI (A ≤ 80, 5-2 MeV/u)</td>
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<td>Germany</td>
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<td>Deutsches Elektronen-Synchrotron (DESY), Hamburg</td>
<td>HERA</td>
<td>Electron (30GeV)-Proton (920 GeV) Collider, pol. e⁻</td>
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<td>Germany</td>
<td>Forschungsneutronenquelle Heinz Maier-Leibnitz, Garching</td>
<td>FRM II</td>
<td>Research Reactor / n (8x10¹⁸ s⁻¹ cm⁻²)</td>
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<td>Germany</td>
<td>Forschungszentrum Juêlich (FZJ), Juêlich</td>
<td>COSY</td>
<td>Cyclotron (acc.-cooler) / pl. p,d/0.27 - 3.7 GeV/c</td>
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<td>Germany</td>
<td>Gesellschaft fuer Schwerionenforschung (GSI), Darmstadt</td>
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<td>Linac-Synchrotron-Storage Ring / p (4.7 GeV) / HI/RIBs (2 GeV/u)</td>
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<td>S-DALINAC</td>
<td>Electron-Linac (acc. + recirculating) / 2-130 MeV</td>
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<td>Germany</td>
<td>University of &amp; Technical University of Munich, Garching</td>
<td>Maier-Leibnitz Laboratory</td>
<td>Tandem (14MV) / p (28 MeV) / HI (9-1.1 MeV/u)</td>
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<td>Germany</td>
<td>University of Bonn, Bonn</td>
<td>ELSA</td>
<td>Electron-Synchrotron/Storage-Stretcher Ring/0.5 - 3.5 GeV</td>
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<td>Germany</td>
<td>University of Cologne, Cologne</td>
<td>Tandem Accelerator</td>
<td>Tandem (10MV) / p (20 MeV) / HI (As80, 6-1.5 MeV/u)</td>
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<td>Germany</td>
<td>University of Mainz, Mainz</td>
<td>MAMI Accelerator</td>
<td>Microtron (e⁻ cw-race track) / 180-1500 MeV</td>
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<td>Inst. of Nucl. Res. of the Hungarian Academy of Sciences, Debrecen</td>
<td>ATOMKI</td>
<td>Cyclotron (K=20) / p(20 MeV) / ³He(27 MeV)</td>
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<td>National Institute of Nuclear Physics (INFN), Assergi</td>
<td>Laboratori Nazionali del Gran Sasso</td>
<td>Electrostatic Acc. 50 kV &amp; 400 kV / deep underground facilities</td>
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<td>Tandem 15 MeV / p (20 MeV) / HI (HI / HI) / S.C. Cyclotron / p (60 MeV) / HI (80-20 MeV/u)</td>
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<td>Synchrotron-Storage-Collider-Ring (e⁻ e⁺) / 1020 MeV cm energy</td>
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<td>Tandem (15 MV) &amp; S.C. Linac / p (30 MeV) / HI (20-6 MeV/u)</td>
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<td>Norway</td>
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<td>Cyclotron (K=35) / p (35 MeV) / He (35 MeV)</td>
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<td>Cyclotron (K=10.5 &amp; K=100) / p (18 MeV) / HI (11SA540 5-2 MeV/u)</td>
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<td>National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest-Magurele</td>
<td>FN Tandem Van de Graaff</td>
<td>(9 MV) / p (18 MeV) / HI (5-0.5 MeV/u)</td>
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<td>Collider (e⁻ e⁺) / 5.5 GeV beam / Gamma rays (tagged 30 – 3500 MeV)</td>
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<td>VEPP-3</td>
<td>Electron (positron) storage ring / (350 MeV-2 GeV) / internal target</td>
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<td>IHEP-Protvino</td>
<td>U-70</td>
<td>Cyclotron : protons and light ions 70 GeV</td>
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<td>Petersburg Nuclear Physics Institute, Russ. Acad. Sciences, Gatchina</td>
<td>PNPI Synchro-Cyclotron</td>
<td>Synchro-cyclotron / p (1000 MeV) / n (&lt;200 MeV) / pions / muons</td>
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<td>INR-Troitsk</td>
<td>MMF</td>
<td>Linac : protons 200-500 MeV</td>
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<td>Underground laboratory at 100, 600, and 4800 mwe</td>
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<td>BUNT</td>
<td>Underwater laboratory at 1300 m</td>
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<td>Nuclotron</td>
<td>Superconducting Synchrotron : 6 Gev/A</td>
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<td>Lund University, Lund</td>
<td>MAX-LAB : Electron Linac (250 MeV) / stretcher / tagged photons (20–225 MeV)</td>
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<td>Switzerland</td>
<td>CERN, Geneva</td>
<td>LHC – ALICE : Pb Pb collisions at 5.5 ATeV</td>
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<td>CERN, Geneva</td>
<td>ISOLDE : Radioactive beams</td>
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<td>Paul Scherrer Institute, Villigen</td>
<td>Isochronous Cyclotron : Cyclotron / p (590 MeV, ≤12 MW) / low-energy pions / muons</td>
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<td>SNOLAB</td>
<td>Underground solar neutrino laboratory / SNO heavy-water</td>
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<td>TRIUMF, Vancouver, BC</td>
<td>Cyclotrons (K=13 - 500) &amp; ISOL Linac / p (500 MeV) / RIBs (6 MeV/u)</td>
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<td>Mexico</td>
<td>Universidad Nacional Autonoma de Mexico UNAM, Mexico City</td>
<td>Van de Graaff Laboratory : p-Ar (&lt;700 KeV) / p-He (1-5.5 MeV)</td>
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<td>USA</td>
<td>Argonne National Laboratory (ANL), Chicago</td>
<td>ATLAS : SC-Linac &amp; tandem injector / p (18 MeV) / HI (6sAs238 16-8 MeV/u)</td>
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<td>Brookhaven National Laboratory (BNL), Upton, NY</td>
<td>RHIC : Collider / p (250 GeV+250 GeV) / HI (A=d-Au 100 GeV/u +100 GeV/u)</td>
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<td>Florida State University, Tallahassee, FL</td>
<td>Superconducting Accelerator Laboratory : Tandem(9 MV) - SCLinac (11 MV)</td>
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<td>Hope College, Holland, MI</td>
<td>HIBAL : Tandem (1.7 MV) / p (3.4 MeV) / p-He (5.1 MeV)</td>
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<td>Institute for Nuclear Theory, Seattle, WA</td>
<td>INT : Theory Institute</td>
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<td>Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA</td>
<td>88-inch Cyclotron : Cyclotron (K=55) / p (55 MeV) / HI (6sAs≤209 32-4.5 MeV/u)</td>
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<td>Michigan State University, East Lansing, MI</td>
<td>NSCL : SC-Cyclotrons (coupled, K500, K1200) / HI RIBS (16≤As≤238 E=160-80 MeV/u)</td>
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<td>National Institute of Standards &amp; Technology (NIST), Gaithersburg, MD</td>
<td>NCNR</td>
<td>Research Reactor / cold neutrons (2 \times 10^9 \text{s}^{-1} \text{cm}^{-2})</td>
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<td>Ohio University, Athens, OH</td>
<td>Edwards Accelerator Laboratory</td>
<td>Tandem accelerator (4.5 \text{ MV})</td>
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<td>Pacific Northwest National Laboratory, Richland, WA</td>
<td>IGEX Detector</td>
<td>Enriched isotope double beta decay</td>
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<td>Sanford Underground Research Facility, Lead, SD</td>
<td>SURF</td>
<td>Underground laboratory at 4300 m.w.e.</td>
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<td>Texas A&amp;M University, College Station, TX</td>
<td>Cyclotron Institute</td>
<td>Cyclotrons (K=150 K=500) / d – U ((70 \text{ MeV/u} – 15 \text{ MeV/u}) / \text{RIBs})</td>
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<td>Thomas Jefferson National Accelerator Facility, Newport News, VA</td>
<td>CEBAF</td>
<td>Electron Facility ((6 \text{ GeV CW SC-Linac recirculator}) / 10\ kW FEL</td>
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<td>Triangle Universities Nuclear Laboratory, Durham, NC</td>
<td>TUNL</td>
<td>Tandem ((10 \text{ MV}) &amp; \text{LEBAF/LENA} (0.2 -1 \text{ MV}) / \text{p,d,He})</td>
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<tr>
<td></td>
<td>University of Kentucky, Lexington, KY</td>
<td>Accelerator Laboratory</td>
<td>Single-ended dc accelerator ((7 \text{ MV}) &amp; \text{He} (7-12 \text{ MeV}))</td>
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<tr>
<td></td>
<td>University of Notre Dame, Notre Dame, IN</td>
<td>Nuclear Structure Lab. (NSL)</td>
<td>Tandem ((10.5 \text{ MV}) &amp; \text{KN Van de Graaff} (4 \text{ MV}) / \text{p(21 \text{ MeV}) / HI (&lt;100 \text{ MeV})})</td>
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<td></td>
<td>University of Washington, Seattle, WA</td>
<td>CENPA</td>
<td>Tandem ((9 \text{ MV}))</td>
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<tr>
<td></td>
<td>Western Michigan University, Kalamazoo, MI</td>
<td>Tandem Accelerator Laboratory</td>
<td>Tandem ((6 \text{ MV}) / \text{p(12 \text{ MeV}) / HI (A&lt;60 3-0.7 \text{ MeV/u})})</td>
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<tr>
<td>SOUTH AMERICA</td>
<td>Argentina</td>
<td>CNEA Physics Department, Buenos Aires</td>
<td>TANDAR Laboratory</td>
<td>Tandem ((20 \text{ MV}) / \text{p(28 \text{ MeV}) / HI (A=6-200, 7-1.4 \text{ MeV/u})})</td>
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<tr>
<td></td>
<td>Brazil</td>
<td>Catholic University, Rio de Janeiro</td>
<td>Van de Graaff Laboratory</td>
<td>Van de Graaff ((4 \text{ MV, single-ended}) / \text{p (4 \text{ MeV}) / HI (A&lt;40, 1 \text{ MeV/u})})</td>
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<tr>
<td></td>
<td></td>
<td>University of São Paulo, São Paulo</td>
<td>LAFN</td>
<td>Tandem ((8 \text{ MV}) (SC Linac u. constr.) / \text{p(16 \text{ MeV}) HI (A&lt;30, 5-3 \text{ MeV/u})})</td>
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<tr>
<td></td>
<td>Chile</td>
<td>Comision Chilean de Energia Nuclear, Santiago</td>
<td>Centro Nuclear La Reina</td>
<td>Cyclotron ((K=18) / \text{p (18 \text{ MeV}) / d (9 \text{ MeV})})</td>
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<tr>
<td></td>
<td></td>
<td>University of Chile, Santiago</td>
<td>Van de Graaff Accelerator Laboratory</td>
<td>Van de Graaff ((3.75 \text{ MV}) / \text{p-Xe (3.5 \text{ MeV})})</td>
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</tbody>
</table>
Scientific Mission and Research Programs:

(a) Vision
To be the leading African organisation for research, training and expertise in accelerator based sciences and technologies.

(b) Mission
To provide state of the art facilities and programmes for high quality research, training and services in nuclear sciences and applications for the benefit of the people of South Africa and the continent in general.

Research programmes include Nuclear and Accelerator Physics, Materials Research, Medical Physics and development of Radionuclides.

Layout of the iThemba LABS cyclotron facility
Characterization of the facility:

200 MeV Separated Sector Cyclotron

Beams delivered at iThemba LABS

**CYCLOTRON OPERATING SCHEDULE**

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Nuclear Physics</th>
<th>Isotopes</th>
<th>Energy chg</th>
<th>Protons</th>
<th>Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>05h15</td>
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<tr>
<td>17h00</td>
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</tbody>
</table>

**Brief and compact table with the facility’s major experimental instrumentation and its capabilities:**

1. Magnetic spectrometer:
   
   K=600 QDD with kinematic correction
   
   Angular acceptance 50msr, momentum byte 9%
   
   x and y vertical drift chambers and plastic scintillators in focal plane
   
   Energy resolution 1/9000 at 200 MeV

2. Afrodite gamma detector array
   
   9 clover detectors (EurogamII type) with BGO escape suppression
   
   8 4-fold segmented planar Ge detectors
   
   efficiency 1.6% at 1.33 MeV and 11% at 100 keV

3. A collimated fast neutron beam facility
   
   Neutrons from p + ⁷Li or ⁹Be at Eₚ up to 200 MeV

for 66 MeV Protons

- Beam current on target: 100 µA
- Transmission efficiency: 99.9%
4. A large multi-purpose scattering chamber (1.2 m diameter)

**Nature of user facility:**
Yes, by the NRF.

**Program Advisory Committee/experiment proposals:**
Yes

**Number of active users and their origin:**
Number is based on actual use of facilities and collaborations with partners.
212 International
225 National
437 Total

Note: These are external users.

**Percentage of users, and percentage of facility use (these numbers may differ) that come from inside the institution:**

<table>
<thead>
<tr>
<th>% Users</th>
<th>% Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Percentage of users and percentage of facility use from national users:**

<table>
<thead>
<tr>
<th>% Users</th>
<th>% Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.5%</td>
<td>60.0%</td>
</tr>
</tbody>
</table>

**Percentage of users and percentage of facility use from outside the country where facility is located:**

<table>
<thead>
<tr>
<th>% Users</th>
<th>% Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.5%</td>
<td>40.0%</td>
</tr>
</tbody>
</table>

**Fraction of the international users outside of geographical region:**
48.5%

**User Group:**
Cape Town (Cyclotron Physics Group): 58
Cape Town (Materials Research Group): 108 users

who are automatically part of the users group.

There is an official Users Advisory Committee comprising of eight members, chosen from disciplines to represent all users.

iThemba LABS (Gauteng): Yes, established recently. No records available. Currently rebuilding user base.

**Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):**

a) Permanent: 285
b) Temporary: 15
c) Postgraduates: 200

**Number of theoretical staff employed at the facility: permanent, postdoctoral, students:**
12 (twelve)

**Number of postdoctoral researchers:**
13 (thirteen)

**Number of graduate students resident at the facility:**
50 (fifty)

**Number of non-resident graduate students with thesis work primarily done at the facility:**
150 (one hundred and fifty)

**Special student programs:**
Under-graduate and graduate vacation work during mid-year break and year-end (± one month).

**Future Plans:**
- New ECR Ion Source
- Major Radiation Medicine Centre: Seeking external funds (US$100m)
- AMS Facility at iThemba LABS (Gauteng)
SOUTH AFRICAN NUCLEAR ENERGY CORPORATION LIMITED (NECSA)

Beam line facilities at the SAFARI-1 research reactor
Beam line facilities at the Van de Graaff accelerator
RFQ-LINAC based beam line facilities

30 km west of Pretoria, North West Province, South Africa

PO Box 582
Pretoria 0001
South Africa

Dr N. Jarvis, Acting Executive Divisional Manager
Telephone: +27 12 305-5631
Facsimile: +27 12 305-5925
E-mail: neil.jarvis@necsa.co.za

Limited liability company under South African law

South African Government, through the Department of Minerals and Energy

Mr G Tshelane, Chief Executive Office

Heads of the facilities:

SAFARI-1 Research Reactor: Mr. B.J. Steynberg
Beam Line Facilities of SAFARI-1 Research Reactor: SANS - Dr A.M Venter
Diffraction - Dr A.M. Venter; Radiography and Tomography - Mr. F.C. de Beer
Van de Graaff Accelerator; Dr C.B. Franklyn

Scientific Mission and Research Programs:

Scientific mission:

To maintain, develop and exploit beam line instrumentation based at the SAFARI-1 research reactor, at the Van de Graaff accelerator and at the RFQ based fast neutron facilities for research by the South African and African research and innovation communities and to act as platforms for post-graduate training.

Current research programs:

Application of non-destructive neutron and X-ray radiography and tomography imaging methods for scientific investigations in the fields of, heritage studies, porous media, mineralogy, engineering materials and bio-sciences and with own research applications in nuclear materials and in particular the study of waste encapsulation material properties.

Investigations of crystalline systems with neutron diffraction for crystallography, chemical composition, magnetism and residual stress determination. The neutron strain scanner (commissioned) and neutron powder diffraction system (near completed) at the SAFARI-1 research reactor is intimately linked with equivalent X-ray diffraction instruments existing within the diffraction group to exploit complementarity.

Materials analysis using the Van de Graaff beam lines, utilizing techniques such as RBS and PIXE to determine elemental compositions and thin film thickness on a variety of geological and other samples.

Fast neutron radiography based on impinging of a deuteron beams (RFQ-LINAC accelerator system) on gas and solid targets. Mono-energetic (tunable energy) neutron beams are available to perform research in the field of fast neutron radiography. Specific projects are complementary to thermal
neutron imaging, but with elemental specificity through nuclear interaction, higher penetrability and thus the added capability to research contra-band and nuclear forensics applications.

**Future Research Programs:**

Analytical investigations of polymers, natural fibres (such as wool and other agricultural materials) and nano-materials with small angle neutron scattering.

Neutron diffraction parametric studies of material properties and performance under conditions associated with their practical use, such as temperature from as low as 3.5 K to as high as 1800 K and in-situ loading up to 50kN.

Magnetic ordering investigations of thin films deposited on single crystal substrates using neutron diffraction methods.

Quantifying fluid flow phenomena within the trickle bed flow regime with radiography/tomography methods.

Increased technique development to support the active South African heritage studies communities.

**Technical facilities:**

SAFARI-1: The SAFARI-1 beam line facilities encompass a SANS facility still under construction, two neutron diffraction instruments (strain scanner and PD) and a radiography/tomography facility (Fig. 1).

At the neutron diffraction facility (Fig. 2) a single radial beam line from the SAFARI-1 research reactor is selectively directed to two independent instruments located around the monochromator chamber M. The facilities are applied to residual strain scanning (left) and powder diffraction (right). The beam delivery from the reactor core has been substantially upgraded with the development of a new beam shaper channel to condition the beam from the reactor core in conjunction with double focused monochromator crystals.

The radiography and tomography facility utilizes thermal neutrons, gamma rays or epi-thermal/fast neutrons as source and a digital CCD camera/scintillator detection unit.

Van de Graaff: The beam line facilities are equipped for fast neutron science, ion beam analysis and PIXE (particle induced X-ray emission) investigations.

RFQ based fast neutron accelerator: RFQ LINAC based fast neutron accelerator (Fig. 5) produce mono energetic neutrons for fast neutron radiography studies.
Characterization of facilities:

SAFARI-1 research reactor: 20 MW pool-type light water cooled and moderated.

Neutron Diffraction: Monochromatic thermal neutron beams in the wavelength range 1 – 2 Å (energy range 10 – 100meV) extracted through the use of large single crystal monochromators from the reactor fission spectrum.

Radiography & tomography: 93% thermal neutron digital radiography/tomography facility equipped with filter systems to also utilise fast neutrons and gamma rays.

Fast neutron accelerator facility: RFQ – LINAC accelerator with neutron production targets.

Van de Graaff accelerator: 4MV; used for ion beam analysis and fast neutron scattering studies.

SANS instrument: Sub-thermal (neutron velocity selection) 9 m SANS instrument with wavelength range (3 – 10 Å) but operated at ~ 3 Å form most applications for intensity purposes.

Facility parameters:

<table>
<thead>
<tr>
<th>SAFARI-1 beam line facilities</th>
<th>Description</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANS (under construction)</td>
<td>Beam species: Thermal to slow neutrons within wavelength range: 3-10 Å selectable by velocity selector.</td>
<td></td>
</tr>
<tr>
<td>Radiography &amp; Tomography</td>
<td>Thermal neutron beam: 300 mm diameter at collimator exit; distance from aperture (L= 2465 mm); three aperture sizes (D) allows (L/D = 150, 300, 500); thermal flux =1.2 × 10⁻⁷ cm⁻².s⁻¹ at L/D = 150; 3.2° maximum beam divergence (D=21 mm).</td>
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<tr>
<td></td>
<td>Gamma beam and fast neutron beam can be allowed to impinge on sample</td>
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</tbody>
</table>

| Neutron Diffraction           | Thermal monochromatic neutrons with selectable wavelength (1 – 2 Å) and resolution via double focused single crystal monochromators. Independent instrumental setups for powder diffraction and strain scanning. Neutron flux at sample position ~ 10⁶ cm⁻².s⁻¹. |

| Van de Graaff accelerator    | Energy: 0.6 – 4 MV |
|                              | Beam species: H⁺, D⁺, He⁺⁺, He⁺⁺⁺, N⁺⁺⁺⁺ |
|                              | Beam current: nA - 200µA |

| Fast neutron accelerators    | RFQ-Low power Dual energy RFQ LINAC with a primary 4 MeV RFQ accelerator and a 1 MeV RFQ accelerator coupled to the end. It produces a maximum beam current of 50 mA at a duty cycle of 20%. Pulsed D-beam energy varies between 3.2 and 5 MeV. A proton beam, at half the energy, can also be delivered. |

Major experimental instrumentation and capability:

<table>
<thead>
<tr>
<th>SAFARI-1 beam line facilities</th>
<th>Neutron Strain Scanner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>Capability</td>
</tr>
<tr>
<td>Neutron beam optics: Double focused Si multi-wafer monochromator; adjustable horizontal focus for optimization at specific diffraction angles in range 30° &lt; 2θ &lt; 110°.</td>
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<tr>
<td>Goniometer: 5 axis high precision Huber unit enabling θ, 2θ, x, y, z with all motion stages with absolute encoders. A full vertical circle stage enabling χ and φ motions can be added.</td>
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<tr>
<td>Detector: 300 x 300 mm² area with 2 mm horizontal and 5 mm vertical resolution respectively.</td>
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<tr>
<td>Instrument control system: GUMTREE /SICS.</td>
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<tr>
<td>Resolution: Δd/d &lt; 10⁻³.</td>
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<tr>
<td>Applications: Strain scanning &amp;</td>
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<tr>
<td>Powder Diffraction (continued)</td>
<td>Texture</td>
</tr>
<tr>
<td>-------------------------------</td>
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</tr>
<tr>
<td>Beam optics: Double focused Si multi-wafer monochromator; adjustable horizontal and vertical focus°.</td>
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<tr>
<td>Goniometer: 5 axis high precision Huber unit enabling 0, 2θ, x, y, z with absolute encoders. A full vertical circle stage enabling χ and φ motions can be added.</td>
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<tr>
<td>Detector: Vertical array of horizontal position sensitive detectors covering 660mm horizontal x 380 mm vertical with 2 mm horizontal and 25 mm vertical resolutions respectively. Sample detector distances are variable within the detector shielding enabling high intensity and high resolution options with respective 20 subtending 30° and 20°.</td>
<td></td>
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<tr>
<td>Instrument control system: GUMTREE/ SICS.</td>
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<tr>
<td>Instrumental resolution: Δd/d better than 10° take-off angle dependent.</td>
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<tr>
<td>Applications: Chemical phase identification; Crystal structure through Rietveld refinement; Investigation of magnetic phenomena in materials</td>
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<tr>
<td>Neutron radiography and tomography</td>
<td></td>
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<tr>
<td>Thermal neutron scintillation screen AST (UK): 25 cm × 25 cm, intrinsic resolution 100 μm, 0.4 mm spatial resolution, 450 nm peak wavelength. Camera: ANDOR Technology DV434’ Peltier cooled, 1024 × 1024 pixel array, 13 μm pixel size, 80% quantum efficiency at 450 nm.</td>
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</table>

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIXE</td>
<td>Determination of elemental composition of materials</td>
</tr>
<tr>
<td>Rutherford Backscatter</td>
<td>Materials and thin film analysis</td>
</tr>
<tr>
<td>Fast neutron detection</td>
<td>Generation and measurement of fast neutrons for radiography and activation analysis</td>
</tr>
<tr>
<td>Isotopic sources</td>
<td>Material characterization and student training</td>
</tr>
<tr>
<td>RFQ-LINAC based Fast neutron accelerators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RFQ neutron source</td>
</tr>
<tr>
<td></td>
<td>Fast neutron isotope production</td>
</tr>
<tr>
<td></td>
<td>Neutron interaction studies</td>
</tr>
<tr>
<td></td>
<td>Digital solid state camera</td>
</tr>
<tr>
<td></td>
<td>Digital energy dependent radiography; illicit material detection, mineral exploration</td>
</tr>
<tr>
<td></td>
<td>SANS</td>
</tr>
<tr>
<td></td>
<td>9meter sub-thermal (not cold) neutrons in wavelength range 3-10 Å for nano-particle and fibrous materialstudies.</td>
</tr>
</tbody>
</table>

Is the facility considered to be a user facility (officially and by whom; unofficially?). With user facility is meant a facility with users from other institutions or laboratories:

Yes, all of the above facilities are officially viewed as user facilities by Necsa, but do not have official national facility status. Facilities are freely available to users from academia and on a proprietary base to industry.

Does the facility have a Program Advisory Committee or the equivalent, adjudicating proposals for experiments?

Planned but not yet formally implemented. Proposals are adjudicated by an internal review process. Completed user office facility will be on-line.

Number of actual, active users of the facility in a given year (an average over the last few years, or just the last year if the facility is new). Please indicate how the number is derived):

SANS: 1 now, up to 5 envisaged
Diffraction: up to 10 (university users as indicated per questionnaire)
Radiography: Up to 50 (based on actual figures from X-ray facilities)
Van de Graaff: 5 nuclear beam analysis
Fast neutron science: 1 now, 5 envisaged

Percentage of users, and percentage of facility use (these numbers may differ) that come from inside the institution (if no statistics exist, please give an estimate but indicate this as such):

SANS: Users: 100%, Facility use: facility development
Radiography: Users: 10%, Facility use: 5%
Diffraction: Users: 10%, Facility use: 10%
Van de Graaff: Users: 50%, Facility use: 50%
Percentage of users and percentage of facility use from national users:

SANS: Users: 0%, Facility use: 0%
Radiography: Users: 90%, Facility use: 95%
Diffraction: Users: 60%, Facility use: 60%
Van de Graaff: Users: 50%, Facility use: 50%

NRAD: 61% National; Use 54% of facility

Percentage of users and percentage of facility use from outside the country where the facility is located:

Currently no users outside South Africa from other African countries.

What fraction of the international users is from outside the geographical region of the facility (i.e. Asia; Australia & New Zealand; North-America; South-America; Africa; Europe):

SANS: Users: 0%, Facility use: 0%
Radiography: Users: 10%, Facility use: 10%
Diffraction: Users: 30%, Facility use: 30%
Van de Graaff: Users: 0%, Facility use: 0%

Does a formal users group with statues and an executive exist for the facility(s) and what is the number of registered members (in general this may be quite different from the number of actual users in a given year):

Planned, not yet implemented

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility(s) and b) temporary staff (including graduate students and postdoctoral researchers on the facility’s payroll):

(a) 20 and (b) 5

Number of theoretical staff employed at the facility: permanent; postdoctoral; and graduate students:

None.

Number of postdoctoral researchers employed by the facility and separately the number of those seconded to the facility by other institutions or laboratories:

None currently.

Number of graduate students resident at the facility (for more than 80% of their time):

On average 10 per year

Number of non-resident graduate students with thesis work primarily done at the facility:

On average 20 per year.

Involvement of undergraduate students in research (approximate average number at a given time):

10

Special student programs, e.g. summer schools, student lecture series, student laboratories, etc. (for high school, undergraduate, and graduate students):

Student laboratory practises for undergraduate and graduate students. Specialised lecture courses as part of university post-graduate degrees.

Describe any plans that exist and their present status for future developments at the facility (facility upgrades; expansions of and new construction for the existing facility, major instrumentation additions, etc.):

Presently a major neutron diffraction facility upgrade program is underway to improve the “useful” neutron beam delivery through neutron beam optics, reduction of background radiation levels for vastly improved peak-to-background ratios, larger beam acceptance with the implementation of area detectors.

The SANS system is under and has a 40 m curved neutron guide tube and a 10 m vacuum chamber to house the scattering and detection system of a 9 m collimated instrument.

The neutron radiography and tomography system has progressed to near completion. Once upgrading is finished it will form part of a national radiography and tomography facility at Necsa for extensive use by the heritage studies communities.
Please provide in brief abstract form any other information that deserve inclusion in the report. Finally, for guidance: the total space devoted to each institution/facility will, most likely, be one full-size page for smaller institutions/facilities and two pages to three pages for larger ones. Here it may be useful to know that it is the intention to precede the individual reports with a few-page summary. In addition, some fraction of the information can and probably will be summarized in general tables and or figures.

With the unavailability of the facility, beam line access is secured at other international user access facilities to ensure maintenance and development of scientific expertise, as well to gain experience in the use of world-leading instruments. This beam line access is secured by peer reviewed project proposals. A number of scientific bi-lateral cooperation agreements are in effect mostly to support mobility of local scientists. Training of technical personnel at international facilities under IAEA fellowships.
Head of the facility:
Zhixiang Zhao

Scientific Mission and Research Programs:
The present research areas of CIAE-DNP are heavy ion physics, nuclear astrophysics, nuclear theory, measurement of nuclear data, application of nuclear physics such as accelerator mass spectroscopy, atomic physics, radiation physics, accelerator technology in the energy range from 2 to 10 A MeV. The BRIF (Beijing Radioactive Ion Beam Facility) project is under construction and includes a 100 MeV, 200 micro A compact proton cyclotron (as a driving machine for unstable nuclei), isotope separator on line and a 2 MeV/q super conducting energy booster after existing 15 MV tandem accelerator (for acceleration of stable and unstable nuclei).

Characterization of the facility:
15 MV tandem accelerator
100 MeV proton cyclotron (will be commissioned in 2014)

Table of facility parameters:
Tandem accelerator
Ion species of Stable nuclei: p to U
Max. Energy: 15 MeV*q
Intensity: up to 2 p micro A
Momentum spread: 30 keV
RIB (A<180): neutron-rich, proton-rich (will be available after 2014)
RIB intensity: 10**(7-12) pps

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:
The major experimental instrumentation includes: radioactive beam line (GIARAFFE), neutron time of flight spectrometer, Q3D heavy ion spectrometer, accelerator mass spectroscopy, in-beam gamma experimental terminal, ECR platform, radiation terminal for materials science research, atomic physics terminal, ion source laboratory and public electronic pool.

Nature of user facility:
BTANPNL is a National Laboratory of China.

**Program Advisory Committee/experiment proposals:**

BTANPNL has a Science Advisory Committee to evaluate experiment proposals and to advise the research activities.

**Number of active users and their origin:**

There are more than 200 formal users in the last five years.

**Percentage of users, and percentage of facility use that come from inside the institution:**

About 30–40% of users come from outside the institute.

**Percentage of users and percentage of facility use from national users:**

About 90% of users are national users, and they use 90% beam-time of the facility.

**Percentage of users and percentage of facility use from outside the country where your facility is located:**

About 10% of users come from outside of China and 10% of facility use from outside of China.

**Fraction of the international users outside of geographical region:**

Up to now the international users are from Asia and North America.

**User Group:**

Most of the users are members of a formal user group and they have had very close collaboration with the institute for a long time.

**Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):**

There are roughly 100 permanent staff and 50 temporary staff.

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**

There are 10 permanent theoretical staff and 10 temporary staff (including post-doctoral fellows, graduate students and long term visiting scientists)

**Number of postdoctoral researchers:**

About 2.

**Number of graduate students resident at the facility:**

About 50.

**Number of non-resident graduate students with thesis work primarily done at the facility:**

About 20 per year.

**Involvement of undergraduate students in research (approximate average number at a given time):**

About 50 per year.

**Special student programs:**

Joint summer school every two years together with universities. Student lectures in universities.

**Future Plans:**

The BRIF project (mainly 100 MeV proton cyclotron) is under construction, and will be commissioned in 2014; and BRIFII project (mainly RFQ-DTL-SC LINAC and experimental facilities) is planned. In the near future they will provide normal and unstable beams up to 10 MeV/u or 34 MeV/q, with a full spectrum of instruments like a versatile magnet spectrometer, Gamma array, decay measurement, large area and micro beam radiation stations. In addition, the Beijing ISOL project is planned in future, and is estimated to be available in the year of 2025. This facility proposed is planned to use both ISOL and PF techniques. It is based on a research reactor CARR that was critical, with ISOL separation of fission fragment, post acceleration to 150 MeV/u, and fragmentation of neutron-rich fission fragment beam like Sn-132. Such unique combination would allow Beijing ISOL to deliver neutron-rich beam intensity better than the best world facilities by order of magnitude.
HEAVY ION RESEARCH FACILITY IN LANZHOU (HIRFL)  
INSTITUTE OF MODERN PHYSICS (IMP)  
CHINESE ACADEMY OF SCIENCES (CAS) /  

Lanzhou, China  

509 Nanchang Road  
730000 Lanzhou China  

Telephone: (0086)-931-4969211  
Telephone: (0086)-931-4969203  
Facsimile: (0086)-931-4969201  
Email: xiaogq@impcas.ac.cn  
Email: huzg@impcas.ac.cn  

National Laboratory Heavy Ion Research Facility in Lanzhou (NLHIRFL)  

HIRFL construction was co-funded by the National Development and Reform Commission of the People’s Republic of China.  
HIRFL operation is fully funded by the Ministry of Finance of the People’s Republic of China.  
HIRFL research is co-funded by Chinese Academy of Sciences (CAS), the National Natural Science Foundation of China (NSFC), Ministry of Education (MOE) of the People's Republic of China and Ministry of Science and Technology (MOST) of the People's Republic of China  

Head of the facility:  
Director of NLHIRFL, Prof. Wenqing Shen.  
Director of IMP, Prof. Guoqing Xiao  

Scientific Mission and Research Programs:  
IMP as a multipurpose research institution, operates an cutting-edge and unique heavy-ion facility for studies in physics, chemistry, biology, medicine, and applied sciences. The best-known results are the discovery of more than 20 new isotopes, the development of a new type of tumor therapy using ion beams and precision mass measurements for short-lived nuclides.  

Characterization of the facility:  
320 kV platform for multi-discipline research with highly charged ions  
SFC cyclotron: K=69 and full ion acceleration  
SSC cyclotron: K=450 and full ion acceleration  
CSRm cooler synchrotron 12.2 Tm  
CSRe cooler storage ring 9.4 Tm
Technical facilities:

Facility Parameters:

**SFC**
- Ion species: Stable nuclei: H, C, U
- Max. Energy: 0.5~10 MeV/u
- Intensity: \(10^{11}~10^{13}\) (pps)
- Momentum spread: \(\pm 5 \times 10^{-3}\)
- Emittance: 25 pimmmrad

**SSC**
- Ion species: Stable nuclei: H, C, U
- Max. Energy: 5~100 MeV/u
- Intensity: \(10^9~10^{12}\) (pps)
- Momentum spread: \(\pm 3 \times 10^{-3}\)
- Emittance: 10 pimmmrad

**CSRm**
- Ion species: Stable nuclei: P - U
- Max. Energy: 2.2 GeV (p), 750 MeV/u
- Energy: \(15^2\)C
- Intensity: \(10^{11-16}\) pps (Stable nuclei, internal target)
- \(10^{7-12}\) pps (RIB, internal target)
- Momentum spread: \(\Delta p / p < 10^{-5}\)
- Experiment mode: Internal-target

**CSRe**
- Ion species: Fully stripped heavy ions: P — Ta
- H-like, He-like heavy ions: Ta — U
- RIB (A<180): neutron-rich, proton-rich
- Max. Energy: 2.2 GeV (p), 750 MeV/u
- Energy: \(15^2\)C
- Intensity: \(10^{11-16}\) pps (Stable nuclei, internal target)
- \(10^{7-12}\) pps (RIB, internal target)
- Momentum spread: \(\Delta p / p < 10^{-5}\)
- Experiment mode: Internal-target

Indispensable devices of HIRFL and their information

HIRFL is composed of two fragmentation separators (RIBLL1, RIBLL2), CSRe internal experimental setup with mass, lifetime measurement and laser instruments, SHE spectrometer, in-beam \(\gamma\) experimental terminal, irradiative terminal for materials science research, irradiative terminal for biology research, cancer therapy terminal, atomic physics terminal. The general and some special instruments, detectors and electronics for nuclear physics, atomic physics,
materials sciences and biology physics are available.

**Property of HIRFL:**

HIRFL is a National Laboratory of China. The average beam time per year is about 7000 hours (70% for experiments, the rest for commission and failure time)

**Program Advisory Committee/experiment proposals:**

HIRFL has a Science Advisory Committee to adjudicate experiment proposals.

**The average number of HIRFL users per year:**

There are more than 200 users in the last five years.

**Percentage of IMP users and their beam distribution:**

About 35% of the users are IMP users and 45% for them.

**Percentage of national users and their beam distribution:**

About 90% of the users are national users, and they use 90% of the beam-time of the facility.

**Percentage of international users and their beam distribution**

There are about 10% of international users and less than 10% beam time is available for them.

**Regional distribution of international users:**

Up to now the international users are from Asia, America, Europe and Africa.

**User Group:**

Most of the users are also IMP’s pateners who have a long-term cooperation with IMP.

**Number of total laboratory staff (all categories) / Scientists on staff with doctoral degree:**

There are about 700 permanent staff and 200 temporary staff.

**Number of theoretical staff employed at HIRFL: permanent; postdoctoral, students:**

There are less than 15 permanent theoretical staff and 40 temporary staff (including post-doctoral fellows, students and the temporary staff of the theoretical centre of the National Lab)

**The average number of postdoctoral researchers per year**

About 10/year.

**The average number of graduate students resident at the facility per year**

About 280/year.

**The average number of non-resident graduate students with thesis work primarily done at the facility per year:**

About 110/year.

**The average number of undergraduate students in research per year**

About 60/year.

**Future Plans:**

In the coming years another international facilities-High Intensity Heavy Ion Accelerator Facility(HIAF) will be built by IMP. HIAF complex consists of a high current superconducting linac (iLinac), a 34 Tm synchrotron (BRing) equipped with electron cooling for beam accumulation, a multifunction experimental storage ring (SRing) and a 43 Tm synchrotron (CRing) for beam compression and stacking. In the high intensity operation mode, the BRing will
be used as booster to increase the beam energy from iLinac to overcome the space charge limit in CRing. The key features of the facility are unprecedented pulse beam intensities and versatile operation mode. The facility will provide intense beams of primary and rare isotopes relativistic heavy ions for a wide range of experiments in particle, nuclear and atomic physics. Rare isotope beams are used to investigate the structure of exotic nuclei, to learn more about nuclear reactions of astrophysical and to measure the mass of nuclei with high precision. High energetic highly bunched heavy ion beams are used to interact with dense plasma to probe the physics of high energy and density matter. Highly charged ions are used for atomic physics programs and a series of applied science.

<table>
<thead>
<tr>
<th>Ion</th>
<th>Max. Energy (GeV/u)</th>
<th>Intensity (ppp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>12.0</td>
<td>3.0×10^{12}</td>
</tr>
<tr>
<td>^{18}O^{6+}</td>
<td>3.2</td>
<td>2.4×10^{12}</td>
</tr>
<tr>
<td>^{78}Kr^{19+}</td>
<td>2.2</td>
<td>1.5×10^{12}</td>
</tr>
<tr>
<td>^{209}Bi^{31+}</td>
<td>1.2</td>
<td>1.1×10^{12}</td>
</tr>
<tr>
<td>^{238}U^{34+}</td>
<td>1.1</td>
<td>1.0×10^{12}</td>
</tr>
</tbody>
</table>
SHANGHAI LASER ELECTRON GAMMA SOURCE (IN THE PLANNING)
SHANGHAI INSTITUTE OF APPLIED PHYSICS, CAS, CHINA

Pudong New District, Shanghai, China

No. 239, Rd. Zhang-heng
Shanghai, 201204, China
Telephone: 86+21-59553998
Facsimile: 86+21-59553021
Email: ygma@sinap.ac.cn

National Lab of China
Chinese Academy of Science
National Natural Science Foundation of China

Director of SINAP: Prof. Zhen-tang Zhao

Head of the facility:
Prof. Yu-Gang Ma; Prof. Wang Xu

Scientific Mission and Research Programs:
We plan to build a low-energy $\gamma$-ray beam line (SLEGS) as one of the Phase-II beamlines of Shanghai Synchrotron Radiation Facility (SSRF) at Zhangjiang Campus, Shanghai Institute of Applied Physics. By Compton scattering of infrared and far-infrared laser lights from 3.5 GeV electrons circulating in the storage ring of SSRF, high intense quasi-monochromatic BCS $\gamma$-rays with high linear or circular polarization ranging both 0.3~15.5MeV and 250~417MeV will be produced. It can be widely applied to fundamental researching fields of nuclear physics and nuclear astrophysics, such as accurate measurement of cross sections of photon reaction in nuclei, nuclear resonance fluorescence experiments, nuclear giant resonances, accurate measurement of the inverse capture cross sections important for astrophysics.

Technical facilities:

Characterization of the facility: MeV BCS $\gamma$-ray source based on Synchrotron Radiation Facility.
Facility Parameters:
beam species: $\gamma$-ray
intensities: $10^5\sim10^7$ s$^{-1}$/ $10^5\sim10^6$ s$^{-1}$
range of energies: 0.3~15.5MeV/250-417MeV
linear or circular polarization: >80%

Nature of user facility:
unofficially

Program Advisory Committee/experiment proposals:
Not yet

Number of actual, active users of the facility in a given year:
No

Percentage of users, and percentage of facility use that come from inside the institution:
No

Percentage of users and percentage of facility use from national users:
No

Percentage of users and percentage of facility use from outside the country where your facility is located:
No

Fraction of international users outside of geographical region:
No

User Group:
No
INTER-UNIVERSITY ACCELERATOR CENTRE  
(FORMERLY KNOWN AS NUCLEAR SCIENCE CENTRE)  

New Delhi, India  

Inter-University Accelerator Centre  
Aruna Asaf Ali Marg  
P.O.Box 10502  
New Delhi-110067  

Telephone: +91-11-26893955  
Facsimile: +91-11-26893666  
E-mail: root@iuac.ernet.in  

Autonomous Inter-University Research Institute of University Grants Commission of India  
University Grants Commission, Department of Science & Technology, Govt of India  

Dr. Amit Roy, Director  

Heads of the facilities:  
Dr. R.K.Bhowmik, Programme Leader, Nuclear Physics; ranjan@iuac.ernet.in  
Dr. D. Kanjilal, Programme Leader, Accelerator; dk@iuac.ernet.in  
Dr. D.K. Avasthi, Programme Leader, Materials Sciences; dka@iuac.ernet.in  

Scientific Mission and Research Programs:  
Inter-University Accelerator Centre (IUAC), an inter-university research institution, was set up by the University Grants commission of India as an autonomous body in the year 1988 with a primary objective of providing a front ranking accelerator-based research facility for undertaking internationally competitive research by university personnel and promoting both basic and applied research in multi-disciplines. Research activities by the user community are in the areas of Nuclear Physics, Materials Science, Atomic Physics and Radiation Biology.  

Technical facilities:  

Figure 1. Arrangement of the QWR cavities in the first Linac module.
Characterization of the facility:
Heavy ion tandem + superconducting linac

Facility Parameters:
Beam Current is in the range of 1-10 pnA for most species Pulsed beams with time width in the range 1ns(for protons) to 2 ns(for heavier ions) at 12 MHz repetition rate are delivered

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Detector Array,</td>
<td>For high-spin spectroscopy. It consists of 12 Compton suppressed HPGe detectors with a 14 element BGO multiplicity detector. It can be augmented with Recoil-distance device, Mini-orange spectrometer and a Charged-particle array.</td>
</tr>
<tr>
<td>Neutron Array,</td>
<td>For neutron multiplicity and energy measurements through time-of-flight. It is a 22 element array of 5&quot; x5&quot; liquid scintillator detectors.</td>
</tr>
<tr>
<td>Heavy Ion Reaction Analyser,</td>
<td>Mass spectrometer for reaction products, Mass resolution ~1/300, Beam rejection ~10^{-12}. has been used for measurement of sub-barrier fusion ans transfer reactions. Used for production of 7Be beam.</td>
</tr>
<tr>
<td>Hybrid Recoil Analyser,</td>
<td>A mass spectrometer for reaction products. Can be operated in either vacuum mode or gas-filled mode. In vacuum mode mass resolution ~1/300 and good efficiency for inverse kinematic reactions. In gas-filled mode good efficiency (~20-30%) for recoils in the mass region ~200.</td>
</tr>
<tr>
<td>Indian National Gamma Array,</td>
<td>A 24 clover Ge detector array is being set-up for high spin spectroscopy. It would have accessories like, plunger for lifetime</td>
</tr>
</tbody>
</table>
measurements, a few planar Ge detectors for low energy gamma detection, a compact charged particle ball. Two-thirds of the array can be coupled to the spectrometer HYRA for recoil tagging.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHV Scanning Tunnelling Microscope, Atomic Force Microscope, Low Temp Cryostat with 8T magnet.</td>
<td>For materials science studies</td>
</tr>
<tr>
<td>Elastic Recoil Detection Analysis, Three-axis Goniometer, In-situ X-ray reflectivity, In-situ photoluminescence, In-situ X-ray Diffractometer.</td>
<td>For on-line materials science interaction studies with swift heavy ions.</td>
</tr>
<tr>
<td>Single &amp; Two foil Beam-foil spectroscopy</td>
<td>Lifetime measurement of electronic states highly charged ions.</td>
</tr>
<tr>
<td>Low Energy Multiply charged ion beams</td>
<td>Multiply charged ion beams in the energy range: a few keV to few MeV. Equipped with two beam lines. Facility for ion implantation, Atomic and Molecular collisions with multiply charged ions, Time of Flight spectrometer, Liquid droplet targets.</td>
</tr>
<tr>
<td>Low-flux irradiation facility, Irradiation in air &amp; Vacuum</td>
<td>The heavy ions from the Pelletron are scattered and diffused to give uniform irradiation over an area with diameter ~3 cm at flux of $10^3$ - $10^7$/cm2/sec.</td>
</tr>
</tbody>
</table>

Nature of user facility:
Yes, it is a user facility of UGC

Program Advisory Committee/experiment proposals:
There is an Accelerator Users Committee which adjudicates the experimental proposals.

Percentage of users and percentage of facility use from national users:
95% of users and 100% facility users are from within the country.

Percentage of users and percentage of facility use from outside the country where your facility is located:
About 5% of users are from outside India.

Fraction of international users outside of geographical region:
100% of the international users are from outside region, viz, Europe and North America

Does a formal users group exist for your facility(s) and what is the number of registered members:
No, there is no registered users group. However, the total number of users is ~ 300 currently.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
a) 100 scientists and technicians
b) 10 graduate students and post doctoral researchers

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
None

Number of postdoctoral researchers:
4

Number of graduate students resident at the facility:
12

Number of non-resident graduate students with thesis work primarily done at the facility:
80 currently

Involvement of undergraduate students in research (approximate average number per year):
None

Special student programs:
Two weeks programmes are held for students at the Masters level, Graduate courses are given for Ph.D. students

Future Plans:
A High Current alternate Injector based on ECR source, Radio-frequency Quadrupole and drift-tube linac is planned.
Also planned are a neutron array and upgrade of the Indian National Gamma Array.
KOLAKATA SUPERCONDUCTING CYCLOTRON (VARIABLE ENERGY CYCLOTRON CENTRE)

Kolkata, West Bengal, India

1/AF, Bidhan Nagar
Kolkata – 700064, India
Telephone: +91 33 2337-1230
Facsimile: +91 33 2334-6871
E-mail : dinesh@vecc.gov.in

Funding for the construction & operation comes from Department of Atomic Energy, Government of India.

Dr. Dinesh Kumar Srivastava, Director

Head of the facility:
Dr. Alok Chakrabarti, Associate Director( Accelerator).

Scientific Mission & Research Program:
The overall mission of the K-500 Superconducting Cyclotron is to provide fore front research opportunities for the scientific community. This cyclotron will deliver heavy ion beams up to 80MeV/nucleon. It will be a national facility for universities and research institutions for undertaking research in nuclear physics, material science, nuclear chemistry, biology etc. Another mission of this project is to gain expertise in development of superconducting magnet and cryogenic technology. The facility will become operational soon.

Technical Facilities:
Electron Cyclotron Resonance (ECR) ion sources will be used to produce ions for acceleration. The ion beam will be injected axially through top of the cyclotron magnet and accelerated by the cyclotron to ~80MeV/A for light ions and ~10MeV/A for heavy ions. There will be four beam lines in the first phase – three for nuclear physics and one for the other experiments.
Facility parameters:
Following table shows the range of beams with expected energy & intensities

<table>
<thead>
<tr>
<th>Beam</th>
<th>Energy (MeV/A)</th>
<th>Maximum intensity (pnA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>80</td>
<td>500</td>
</tr>
<tr>
<td>α</td>
<td>70</td>
<td>500</td>
</tr>
<tr>
<td>Li</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>B,C,N,O,Ne</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>S,Ar</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>Kr</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Xe</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Ta</td>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

User facilities (currently under development):
Main instrumentation for nuclear physics experiments & other experimental programs:

1. Scattering chamber (90cm diameter & 50 cm long, vertical type).
2. 50 detector BaF2 array.
3. CsI charge particle array for gamma ray spectroscopic studies.
4. HPGe detectors
5. Segmented LEPS detector.
6. X-ray diffractometer
7. Target laboratory.
8. Si-detector laboratory.
9. Electronics laboratory.
10. HPLC System,
11. Low background counting laboratory.

Program Advisory Committee /Experimental proposals:
At present the VEC Users’ Committee reviews the experimental proposals.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) 501 (VECC)
b) 46 (VECC)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

Permanent: 11 (VECC)
Postdoctoral: 1 (VECC)
Student: 5 (VECC)

Number of postdoctoral researchers:
3 (VECC)

Number of graduate students resident at the facility (>80% of their time):
28 (VECC)

Number of non-resident graduate students with thesis work primarily done at the facility:
1 (VECC)

Special student programs:
Vacation programs/projects for undergraduate students (Science & Engineering), are organized of durations ~1-2 months.

Future Plans:
1. Scattering chamber (100cm diameter & 200cm long, horizontal type).
2. Charged particle detector array: Each detector in the forward part of the array (covering angular range ~ 5° - 40°) has been planned to be made up of 3 detector elements in telescope configuration. Each detector telescope will consist of (i) thin Si-strip ΔE detector (Size: 5cm x 5cm, thickness: 30 – 50 µm, 16 strips, one-sided), followed by (ii) thick Si-strip ΔE/E detector (Size: 5cm x 5cm, thickness: 500 µm – 1mm, 16 strips, double-sided, X-Y directions), and (iii) 4 CsI(Tl) crystals (Size: 2.5cm x 2.5cm, thickness: 4 – 6cm). Backward part of the array will be consist of ~250 Si+CsI telescopes.
3. Neutron multiplicity detector: Neutron multiplicity detector is a large tank of Gd-loaded liquid scintillator, read out using PMTs. The neutron detector is planned to be designed in such a way that the charged particle array can be placed within the neutron detector, rendering it possible to measure simultaneously the neutrons as well as charged particles.
4. High energy gamma detector array: The array will consist of 162 BaF2 detectors (each of size: 3.5cm x 3.5cm x 35cm).
5. Ion trap: It is used for trapping low energy ions in magnetic field. Typical field required is ~5T, which is planned to be provided by a superconducting solenoid.
6. Multidisciplinary research facility: Low temperature irradiation setup. Acoustic emission setup etc.
VECC has built a low energy ISOL type radioactive ion beam facility around the K130 cyclotron. The aim is to accelerate beams to energy of 1.0 MeV/A. A schematic layout of RIB facility is shown in figure-2. Front-end of the facility consists of a target chamber with integrated ion-source that will be placed inside heavily shielded cyclotron vault. The $1^+$ beam from target/ion-source is further ionized to q+ charge in an Electron Cyclotron Resonance (ECR) ion-source charge-breeder. After mass separation, the selected low energy (1.7 keV/A) RIB is accelerated to 100 keV/A in a Radio Frequency Quadrupole (RFQ) accelerator and thereafter to 415 keV/A in three heavy-ion Linac cavities. Recently radioactive ion beams (RIB) of $^{14}$O (71 sec), $^{42}$K (12.4 hrs), $^{43}$K (22.2 hrs) and $^{41}$Ar (1.8 hrs) have been successfully produced at VECC, using a novel gas-jet recoil transport coupled Electron Cyclotron Resonance (ECR) ion-source technique. The RIB of $^{14}$O has been further accelerated through the RFQ linac to 1.4 MeV. Stable isotope beams such as $^{12}$C, $^{16}$O, $^{14}$N, $^{40}$Ar, $^{39}$K, $^{56}$Fe are also accelerated and are being used for material science experiments.

With the R&D steps towards development of RIB accelerators completed to a great extent, VECC now aims to construct the next generation facility called ANURIB (Advanced National facility for Unstable and Rare Isotope Beams). ANURIB is envisaged as a combined ISOL and fragmentation facility with beam energy from 1.5 keV/A to 100 MeV/A. It will be built around a 50 MeV, 100 kW superconducting electron linac photo-fission driver that VECC is developing in collaboration with TRIUMF laboratory in Canada. The facility will be constructed in stages and initial funding for writing a detailed Technical Design Report on physics & engineering design of components and science plan has been secured.
VARIABLE ENERGY CYCLOTRON CENTRE

Calcutta, India

Sector 1, Block AF
Bidhan Nagar
Calcutta 700 064
India
Telephone: +91 33 23371230 to 33
Facsimile: +91 33 23346871
E-mail: vectldsc@veccal.ernet.in

Under the Department of Atomic Energy (DAE),
Government of India
Funded by DAE

Dr. Bikash Sinha

Head of the facility:
Radioactive Ion Beam Facility at VECC: Alok Chakrabarti

Technical facilities:

VECC RIB Facility
- ISOL type facility; RIB acceleration to 400 keV/u is funded
- Primary accelerator: VEC K130 cyclotron (p, α); 50 MeV Electron-Linac (proposed)
- Present status: stable beams accelerated to 30 keV/u at the end of RFQ; new RFQ for acceleration to 86 keV/u & three IH-Linac tanks to achieve 400 keV/u under construction; thick target and charge breeder R&D continuing
- Group strength 20 – Physicists (7); Engineers (8); Technicians (3); Post-Docs (2)
Program Advisory Committee/ experiment proposals:
International Advisory Committee for SCC and RIB project & Project Implementation Committees have been over-viewing the projects

Special student programs:
Summer Internship programmes for graduate students from Universities, Indian Institutes of Technology and other colleges are conducted

Future Plans
- Acceleration of up to 400 keV/u is expected to be complete by middle of 2008
- In the second phase (year 2008 and beyond), the option of using electron linac for production of neutron-rich RIB through photo-fission route and acceleration of RIB using linacs up to about 6-7 MeV/u is under consideration. Finally, it is proposed to inject the 6-7 MeV/u RI as well as stable beams into a Separated Sector Cyclotron for further acceleration to about 100 MeV/u.
224 CM VARIABLE ENERGY CYCLOTRON (VEC)
VARIABLE ENERGY CYCLOTRON CENTRE (VECC)

Kolkata, India

1/AF, Bidhan Nagar
Kolkata-700 064
India
Telephone: +91 33 2337-1230
Facsimile: +91 33 2334-6871 & 2334 1110
E-mail: bhandari@veccal.ernet.in

VECC is a unit of the Department of Atomic Energy, Government of India
Government of India

Dr. Bikash Sinha, Director

Head of the facility:
Dr. R. K. Bhandari, Associate Director

Scientific Mission and Research Programs:
The 224 cm cyclotron commissioned in 1978 was built to demonstrate indigenous capabilities in the country for constructing a large accelerator. And eventually the cyclotron provided a unique experimental facility for nuclear physics community. During the past several years it has not only provided beams for nuclear physicists but for nuclear chemistry, condensed matter physics, isotope production etc. Presently the cyclotron is mostly used as a heavy ion facility where the ion production is done by Electron Cyclotron Resonance (ECR) ion source. VEC will soon become the primary beam source for the Radioactive Ion Beam (RIB) facility that is currently under construction at VECC.

Technical facilities:
There are four experimental caves. Three beam lines transporting beams to two high intensity caves are generally used for experiments. A 160° magnet will be used to bend the beam for transport to a large cave where the RIB facility is coming up.
Characterization the facility:
The accelerator is an AVF cyclotron with K=130. It accelerates light ion beams and till date has provided beams up to mass no. 40. The beam energy currently ranges from 7*A MeV to 20*A MeV in the first harmonic mode.

Facility Parameters:
In the past PIG ion source was used for producing alpha, proton and deuteron beams. Presently, two external ECR ion sources are used for producing multiply charged ions for injection into the cyclotron using an axial injection line. The two ECR sources have operating frequencies of 6.4 GHz and 14 GHz.

Beams Available:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy (MeV)</th>
<th>Beam Current (nA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>7-10</td>
<td>400</td>
</tr>
<tr>
<td>Alpha</td>
<td>30-65</td>
<td>2500</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>98</td>
<td>120</td>
</tr>
<tr>
<td>Oxygen</td>
<td>110-160</td>
<td>1000</td>
</tr>
<tr>
<td>Neon</td>
<td>140-200</td>
<td>300</td>
</tr>
<tr>
<td>Sulphur</td>
<td>230</td>
<td>60</td>
</tr>
<tr>
<td>Argon</td>
<td>280-340</td>
<td>85</td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:
1. Irradiation chambers – a variety of them
2. 90 cm scattering Chamber for charged particle spectroscopy
3. Detector (array) systems for gamma spectroscopy

Nature of user facility:
It is a national facility available to all research institutions and universities

Program Advisory Committee/experiment proposals:
The VEC Users’ Committee screens the experimental proposals and advises on matters related to utilization of the cyclotron.

Number of actual, active users of the facility in a given year:
Till date about 50 institutions including universities have used the facility. In a typical year 25-30 experimental groups have been given the beam time.

Percentage of users, and percentage of facility use that come from inside the institution:
An average estimate for percentage of inside users = 20%
Percentage of facility use by the inside users = 35%

Percentage of users and percentage of facility use from national users:
Percentage of national users = 80%
Percentage of facility use by the national users = 65%
Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) 470 (VECC)
b) 29 (VECC)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

a) Permanent: 11 (VECC)
b) Postdoctoral: 1 (VECC)
c) Student: 1 (VECC)

Number of postdoctoral researchers:
3 (VECC)

Number of graduate students resident at the facility (>80% of their time):
14 (VECC)

Number of non-resident graduate students with thesis work primarily done at the facility:
2 (VECC)

Special student programs:
Summer training programs for undergraduate students, both engineering as well as science, for a duration of 1 or 2 months are organized.

Future Plans:
The cyclotron is 28 years old. Presently different subsystems of the cyclotron are being upgraded and modernised. The objective is to use the cyclotron as feeder of primary beam to the Radioactive Ion Beam Facility that is under currently construction.
PELLETRON LINAC FACILITY

Mumbai, India

Tata Institute of Fundamental Research
Homi Bhabha Road, Colaba, Mumbai 400005
India
Telephone: +91 22 22804620
Facsimile: +91 22 22782133
E-mail: pillay@tifr.res.in, datar@barc.gov.in

This is joint facility of BARC (unit of Department of Atomic Energy, Government of India) and TIFR (Automonomous Aided Institution of Dept. of Atomic Energy, Government of India)

Head of the facility:
Prof. R.G. Pillay (TIFR), Dr. V.M. Datar (BARC)

Scientific Mission and Research Programs:
The research activities at the facility span a variety of problems in nuclear, atomic, condensed matter physics and interdisciplinary areas. A number of application based research programmes such as accelerator mass spectrometry (AMS) and beam induced radiation damage studies in materials have also been taken up. The research work in nuclear physics, which forms the main thrust of activities at this facility, covers areas of nuclear structure studies at high angular momentum and excitation energies and the heavy ion reaction dynamics.

Technical facilities:
The Facility consists of the 14MV Pelletron accelerator and an indigenously developed superconducting LINAC booster. The Pelletron acts both as a stand alone machine and as an injector to the LINAC. The LINAC consists of seven modules, each module having a liquid He cryostat which houses four lead coated (2 µm) copper quarter wave resonators. The cavities are designed to operate at 150 MHz with an optimum acceptance at a velocity corresponding to $\beta=0.1$. Three different ion sources are available: (i) for negative He ions, (ii) for negative ions of other gaseous elements and (iii) a Cesium sputter ion source for nearly all other elements. An indigenously developed MC-SNICS (Multi-Cathode Source of Negative Ions by Cesium Sputtering) source has been successfully commissioned. A pulsed beam is obtained using a double harmonic drift buncher, built in-house, situated in the low energy injection path of the Pelletron accelerator. The beam bunches have a typical width (FWHM) of 1.5 ns with a separation of 107 ns and has a bunching efficiency of ~66 %. The dark beam current between the beam bunches is swept away by a RF parallel plate sweeper, situated at the exit of the Pelletron. In addition, a beam chopper has also been installed to increase the time duration between bunches (~200 ns – 1.6 µs).

Figure 1: Inside view of a LINAC cryostat showing four quarter wave resonators
Figure 2: A Schematic layout of 14MV Pelletron accelerator and LINAC
Figure 3: Experimental area, namely, User Hall 1 (top) and User Hall 2 (bottom), where both Pelletron and LINAc beams are available.
**Characterization the facility:**

**Beams Available:**

Beams of $^6$, $^7$, $^9$, $^{10}$, $^{11}$, $^{12}$, $^{13}$, $^{14}$, $^{15}$, $^{16}$, $^{17}$, $^{18}$, $^{19}$, $^{20}$, $^{24}$, $^{27}$, $^{28}$, $^{30}$, $^{31}$, $^{32}$, $^{34}$, $^{35}$, $^{37}$ are available through Pelletron and Linac up to 8-10 MeV/A, with an intensity of few pA on target through collimators. Proton beams of up to 24 MeV, ~200 nA are available in the high current irradiation setup. Heavier beams like Iodine, Silver are available through Pelletron. Alpha beam and additional negative ion beams are made available on request.

**Major experimental instrumentation and its capabilities:**

- Clover Detector Array for discrete gamma ray spectroscopy with auxiliary detectors
- 150 cm dia Scattering Chamber for charged particle spectroscopy and fission studies
- BaF$_2$/LaBr$_3$ array for high energy gamma ray studies with BGO/NaI(Tl) multiplicity filter
- 7.0 T superconducting magnet for hyperfine interaction studies.
- Electron spectrometer and X ray detector set up for atomic physics studies with gas/foil targets
- Irradiation setups
- High current proton and neutron irradiation facility
- Low background offline counting facility

**Nature of user facility:**

It is a national facility primarily used by TIFR and BARC scientists and open to collaborators from other research institutions/universities.

**Program Advisory Committee/experiment proposals:**

The Pelletron Linac Programme Implementation Committee (PLPIC) screens the experimental proposals and monitors utilization of the accelerator. The Pelletron Linac Facility Committee (PLFC) deals with overall management of the facility.

**Number of actual, active users of the facility in a given year:**

Till date about 50 institutions including universities have used the facility. Typically ~60 experiments are carried out every year by different groups.

**Percentage of users, and percentage of facility use that come from inside the institution:**

An estimate of the average percentage of inside users is ~ 80%

Percentage of facility use by the inside users ~80%

**Percentage of users and percentage of facility use from national users:**

Percentage of national users ~95%

Percentage of facility use by the national users ~99%

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**

a) 20 (BARC) 25 (TIFR)
b) 30 (BARC) 8 (TIFR)

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**

None associated directly with the facility.

**Number of postdoctoral researchers:**

2 (BARC) 4 (TIFR)

**Number of graduate students resident at the facility (>80% of their time):**

8 (BARC) 8 (TIFR)

**Number of non-resident graduate students with thesis work primarily done at the facility:**

~20

**Special student programs:**

Summer training programs (~2 months) are organised by TIFR for undergraduate students.

Engineering students do their project works in accelerator instrumentation (~ 10 every semester)

**Future Plans:**

The upgrade of HV accelerating tube in the Pelletron is planned to enable operation at a higher voltage and improve the overall performance. It is also proposed to develop low β Nb cavities for two linac modules, to enhance the acceptance of the Linac for heavier beams. Efforts are underway for the development of digital LLRF control for the superconducting cavities.
HEAVY ION MEDICAL ACCELERATOR IN CHIBA (HIMAC)
NATIONAL INSTITUTE OF RADIOLOGICAL SCIENCES

30km east of Tokyo, Japan
4-9-1, Anagawa, Inage-ku, Chiba
263-8555 JAPAN
National Institute of Radiological Sciences

Dr. Takeshi Murakami
Research Program for the Application of Heavy Ions in Medical Sciences
Research Center for Charged Particle Therapy
National Institute of Radiological Sciences
4-9-1, Anagawa, Inage-ku, Chiba
263-8555 JAPAN

Telephone: +81-43-206-3205
Facsimile: +81-43-206-4627
E-mail: muraka_t@nirs.go.jp

Independent Administrative Institution
Government funding
Yoshiharu Yonekura, M.D., Ph.D.

Head of the facility:
Tadashi Kamada, M.D.

Scientific Mission and Research Programs:
National Institute of Radiological Sciences (NIRS) is the institution in Japan dedicated to comprehensive scientific research for radiation and health. The primary purpose of HIMAC is a clinical trial of cancer treatment by heavy ion beams. During 19 years, more than 7,700 patients were treated, being as a leading facility of heavy ion beam therapy in the world. Although the primary purpose is the clinical trial, HIMAC supplies the various beams to experiments of basic research beyond the medical science, during the night and weekend.

Characterization of the facility:
High energy heavy ion beams, up to 800 MeV/u, supplied by linear accelerators and two synchrotron rings.
Technical facilities:

**Facility Parameters:**
The typical parameters from the synchrotron rings.

<table>
<thead>
<tr>
<th>Ion species</th>
<th>Energy (MeV/u)</th>
<th>Intensity (particles / second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>100 - 230</td>
<td>$&lt;1.2 \times 10^{10}$</td>
</tr>
<tr>
<td>C</td>
<td>100 - 430</td>
<td>$&lt;1.8 \times 10^{9}$</td>
</tr>
<tr>
<td>N</td>
<td>100 - 430</td>
<td>$&lt;1.5 \times 10^{9}$</td>
</tr>
<tr>
<td>O</td>
<td>100 - 430</td>
<td>$&lt;1.1 \times 10^{9}$</td>
</tr>
<tr>
<td>Ne</td>
<td>100 - 600</td>
<td>$&lt;7.8 \times 10^{8}$</td>
</tr>
<tr>
<td>Si</td>
<td>100 - 800</td>
<td>$&lt;4.0 \times 10^{8}$</td>
</tr>
<tr>
<td>Ar</td>
<td>290 - 650</td>
<td>$&lt;2.4 \times 10^{8}$</td>
</tr>
<tr>
<td>Fe</td>
<td>400, 500</td>
<td>$&lt;2.2 \times 10^{8}$</td>
</tr>
</tbody>
</table>

Beams from an injector linac, 6 MeV/u, are also available.

**Brief and compact table with the facility's major experimental instrumentation and its capabilities:**

(Caution) In this, and the following descriptions, the clinical treatment part will not be included.

<table>
<thead>
<tr>
<th>Course name</th>
<th>Beam characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Purpose</td>
<td>Thin beams, a few mm in diameter</td>
</tr>
<tr>
<td>Secondary Beam Course</td>
<td>Projectile fragmentations</td>
</tr>
<tr>
<td>Biology Course</td>
<td>Large uniform field, 10cm</td>
</tr>
</tbody>
</table>

**Nature of user facility:**
Yes, it is. The facility announces the call for proposal periodically.

**Program Advisory Committee/experiment proposals:**
Yes, it has. The PAC is composed of scientists outside of NIRS, nominated by scientific societies, institutions, and some on request by NIRS.

**Number of actual, active users of the facility in a given year:**
Users outside of NIRS are around 704, an average value of the last three years. Once proposals are accepted, most of the participants are registered as collaborative researchers of NIRS. The cited number is a total number of registered researchers.

Users inside NIRS are around 165, three years average. These are statistics based on a participant list of each proposal.

Thus the total is 869.
Percentage of users, and percentage of facility use that come from inside the institution:

See the previous answer about the number of users. About 19% (165/869) comes from inside the institution. Facility Use is difficult to answer. As a tip, 27% of spokespersons of total 134 proposals in 2012 were researchers inside the institution.

Percentage of users and percentage of facility use from national users:

See the previous and the next one. About 67% of the users and 55% of the spokespersons come from other institute in Japan.

Percentage of users and percentage of facility use from outside the country where your facility is located:

Foreigners are 120 in 869 registered researchers (14%). Spokespersons from outside Japan is 18%.

Fraction of the international users is from outside your geographical region:

Mainly U.S., Canada, Europe and China. Small numbers come from other Asian countries.

Users Group:

No formal users group exists.

Number of a) permanent staff and b) temporary staff:

(Caution) A lot of medical staff in the hospital are involved in the activity of this facility. Medical staff are, however, excluded when possible in answers to this question or questions hereafter.

a) Around 15, including medical physicists.

b) Around 10

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

None.

Number of postdoctoral researchers:

Around 3 employed by the facility, and others are none.

Number of graduate students resident at the facility:

Around 10

Number of non-resident graduate students with thesis work primarily done at the facility:

Around 20.

Involvement of undergraduate students in research:

Around 20.

Special student programs:

None.

Future Plans:

A superconducting rotating gantry for cancer treatment is under construction.

There are two synchrotron rings working independently. Three groups, if a linac beam is included, can share the beam time, using different beams, simultaneously. Therefore HIMAC can offer relatively long beam time for basic research, about 5,000 hours in 2012.
Head of the facility:
Yujiro Ikeda, Director of J-PARC Center

Scientific Mission and Research Programs:

Japan Proton Accelerator Research Complex (J-PARC) covers a broad range of scientific researches. The main subjects in nuclear and particle physics at J-PARC are neutrino physics, strangeness nuclear physics, hadron physics, kaon decay physics, and muon physics. Experiments are performed mainly at Neutrino experimental facility and Hadron experimental facility. In addition, several experiments are also carried out at Material and Life Science Facility (MLF) with pulsed neutron and muon beams.

The neutrino experimental facility provides the intense muon-neutrino beam to the huge neutrino detector, Super-Kamiokande, which is located 295km away from J-PARC. The T2K (Tokai-to-Kamioka) experiment measures the neutrino flavor change to search for the new neutrino oscillation, and eventually the hints for the $CP$-violation in neutrino.

At the Hadron experimental facility, various nuclear and particle physics experiments are being carried out using a variety of high-intensity hadron beams. Using kaon beams, strangeness nuclear physics and kaon rare decay measurements are being performed. New beam lines are in preparation to perform hadron experiments using a high momentum beam (High-p) and a muon-electron conversion experiment (COMET).

Using high-intensity muon beams at MLF, muon physics experiments such as $g$-$2$ and muon EDM measurements are being planned.

Characterization of the facility:

High-intensity proton accelerators produce high-intensity kaon, neutrino, muon, neutron beams, etc. There are three main experimental facilities: Material and Life Science Facility (MLF), Neutrino experimental facility (NEF), and Hadron experimental facility (HEF). Muon and neutron secondary beams are available at MLF, and kaon and other hadron beams are available at HEF.

Table of facility parameters:

J-PARC’s accelerator complex consists of Linac, Rapid Cycle Synchrotron (RCS), and Main Ring (MR). RCS provides the 3 GeV pulsed proton beam for MLF, and MR provides the 30 GeV proton beam for NEF with fast extraction and for HEF with slow extraction.

<table>
<thead>
<tr>
<th>Acc. Name</th>
<th>Energy</th>
<th>Current (Design) Power</th>
<th>Cycle</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCS</td>
<td>3 GeV</td>
<td>300 kW (1MW)</td>
<td>40 ms</td>
<td>pulsed</td>
</tr>
<tr>
<td>MR</td>
<td>30 GeV</td>
<td>200 kW (750kW)</td>
<td>2.4 s (~ 1s)</td>
<td>fast (8 bunches, beam on 4.2 μs)</td>
</tr>
<tr>
<td>MR</td>
<td>30 GeV</td>
<td>24 kW (100 kW)</td>
<td>6 s</td>
<td>slow (beam on 2sec)</td>
</tr>
</tbody>
</table>
Technical facilities:

In the experimental areas, instrumentations are constructed and operated by the users whose proposal on the experiment was approved by the program advisory committee.

<table>
<thead>
<tr>
<th>Name</th>
<th>Species</th>
<th>Energy</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ν</td>
<td>ν</td>
<td>0.7GeV (Average)</td>
<td>$1.2 \times 10^5 v/cm^2/10^{21}$ pot@SK</td>
</tr>
<tr>
<td>KL</td>
<td>Neutral K</td>
<td>~2 GeV/c</td>
<td>$10^6$ Hz</td>
</tr>
<tr>
<td>K1.8</td>
<td>$\pi^o, K^o$</td>
<td>&lt; 2.0 GeV/c</td>
<td>$10^5$ Hz for K$^+$</td>
</tr>
<tr>
<td>K1.8BR</td>
<td>$\pi^+, K^+$</td>
<td>&lt; 1.0 GeV/c</td>
<td>$10^4$ Hz for K$^+$</td>
</tr>
<tr>
<td>K1.1BR</td>
<td>$\pi^+, K^+$</td>
<td>&lt; 1.1 GeV/c</td>
<td>$10^4$ Hz for K$^+$</td>
</tr>
<tr>
<td>COMET</td>
<td>$\mu^-, \pi^-, e^-$</td>
<td>20-60MeV/c</td>
<td>$3 \times 10^{11}$ Hz for $\mu^-$</td>
</tr>
<tr>
<td>High-p</td>
<td>proton</td>
<td>30GeV</td>
<td>$10^{10}$ Hz</td>
</tr>
<tr>
<td></td>
<td>Unseparated</td>
<td>&lt; 20GeV/c</td>
<td>$10^7$ Hz</td>
</tr>
</tbody>
</table>

Note: K1.8 and K1.8BR shared beam line magnets in the upstream part; the beam can be delivered only one of them at a time.

Neutrino beam is available at NEF and other beams are delivered to HEF.

New muon beam line (H-Line) is planned at MLF to perform new experiments.
Nature of user facility:
International user facility

Program Advisory Committee/experiment proposals:
There are two Program Advisory Committees. One is for nuclear and particle physics experiments with 30 GeV protons from MR, and the other is for material and life science experiments with 3 GeV protons from RCS.

Number of actual, active users of the facility in a given year:
1,282

Percentage of users, and percentage of facility use that come from inside the institution:
7%

Percentage of users and percentage of facility use from national users:
32%

Percentage of users and percentage of facility use from outside the country where your facility is located:
51%

Fraction of the international users is from outside your geographical region:
33%

User Group:
Hadron Hall User Association for HEF, T2K collaboration for NEF, Nuutron and Muon users communities for MLF

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 84  b)  68

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
10

Number of postdoctoral researchers:
5

Number of graduate students resident at the facility:
10

Number of non-resident graduate students with thesis work primarily done at the facility:
50

Involvement of undergraduate students in research (approximate average number per year):
10 as summer students or under the internship programs,

Special student programs:
The Graduate University for Advanced Studies (SOKENDAI) has departments and Ph.D courses in particle physics, nuclear physics, and material and life sciences. KEK staffs can accept and supervise graduate students through it.

Future Plans:
New hadron physics experiments and muon experiments will be performed using the new beam line at HEF. The facilities have following upgrade plans.
- New beam line at MLF
- Increase of main ring power for the neutrino experiment.
- Extension of Hadron Hall and add more beam lines
Kamioka Observatory

Geographic location: 36°25′32.6″N, 137°18′37.1″E
1000m underground beneath the peak of Mt. Ikenoyama

Kamioka Observatory, ICRR
University of Tokyo
456 Higashi-Mozumi, Kamioka, Hida, Gifu 506-1205, Japan
Telephone: +81-578-85-9601
Facsimile: +81-578-85-2121
E-mail: webmaster@km.icrr.u-tokyo.ac.jp

A University Institute

Main source of funding for construction from a Government Budget allocation and for operation from a Government Budget allocation and Grant-in-Aid for Scientific Research

Professor Yoichiro Suzuki, Director

Scientific Mission and Research Programs:

The Super-Kamiokande detector is located in this observatory. It is a 50 kton water Cherenkov detector studying the neutrino mass and mixings, proton decay and astrophysical phenomena from the sun and supernova by means of neutrino detection.

The Kamioka Observatory has expanded its role and now it operates XMASS, a direct dark matter search experiment. The Kamioka Observatory also accepts experimental proposals to use underground spaces from external research institutions. CANDLES is a double beta decay experiment using $^{48}$Ca led by Osaka University and NewAGE is a dark matter experiment led by Kobe University to detect the direction of recoil nuclei.

Technical facilities:
Characterization of the facility:

The Kamioka Laboratory is a deep-underground facility for astroparticle physics.

Facility Parameters:

1000 m (2700 m.w.e.) underground
muon rate at the facility: $6 \times 10^{-8}$ cm$^{-2}$s$^{-1}$sr$^{-1}$

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

- Super-Kamiokande: 50 ton water Cherenkov detector
- XMASS: Multi-purpose (dark matter search and etc.) detector using liquid xenon
- CANDLES: Double beta decay experiment using $^{48}$Ca
- NEWAGE: Dark matter experiment to detect directions of recoil nucleus

Is the facility considered to be a user facility?

Yes, it is a user facility officially.
Does the facility have a Program Advisory Committee?

Yes, ICRR has a committee to select proposals, and the observatory has a committee to discuss practical issues at the underground site.

Number of actual, active users of the facility in a given year:

About 219 (total number of experimental members in 2012).

Percentage of users, and percentage of facility use that come from inside the institution:

18% (percentage of users is same as that of facility use)

Percentage of users and percentage of facility use from national users:

67% (percentage of users is same as that of facility use)

Percentage of users and percentage of facility use from outside the country where the facility is located:

33% (percentage of users is same as that of facility use)

What fraction of the international users is from outside the geographical region of the facility:

18%

Does a formal users group with statues and an executive exist for the facility?

There is no formal users group

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff (including graduate students and postdoctoral researchers on the facility’s payroll):

a) Totally 15 (13 permanent research staff, 2 administrative permanent staff)
b) Totally 26 (9 temporary research staff, 4 temporary administrative staff, 3 temporary technical staff, 1 temporary outreach staff, 9 graduate students)

Number of theoretical staff employed at the facility: permanent; postdoctoral; and graduate students:

Zero

Number of postdoctoral researchers employed by the facility and separately the number of those seconded to the facility by other institutions or laboratories:
Number of postdoctoral researchers: 8
Those seconded by other institutes: 0

Number of graduate students resident at the facility (for more than 80% of their time):
5 (as of September 2013)

Number of non-resident graduate students with thesis work primarily done at the facility:
49 non-resident Ph.D. graduate students from 1996 to 2013

Involvement of undergraduate students in research (approximate average number at a given time):
No undergraduate students except for a few internship-like students per year

Special student programs, e.g. summer schools, student lecture series, student laboratories, etc. (for high school, undergraduate, and graduate students):
Lectures for science high school students (several schools per year)

Describe any plans that exist and their present status for future developments at the facility (facility upgrades; expansions of and new construction for the existing facility, major instrumentation additions, etc.):
A megaton-size water Cherenkov detector, Hyper-Kamiokande, is proposed.

Please provide in brief abstract form any other information that deserve inclusion in the report:
The Kamiokande detector, which was running from 1983 to 1996, was the origin of this observatory. The Kamioka Observatory was established in 1995 to push forward with the Super-Kamiokande experiment. Main physics achievements obtained here are observation of supernova neutrinos from SN1987A, discovery of neutrino oscillations using atmospheric neutrinos (1998) and solar neutrinos (2001), confirmation of the neutrino oscillations by the K2K long baseline neutrino experiment (2004), and the determination of the last mixing angle by detecting the electron neutrino appearance at the T2K experiment (2011).
RESEARCH CENTER FOR NUCLEAR PHYSICS, OSAKA UNIVERSITY

Osaka, Japan

10-1 Mihogaoka, Ibaraki
Osaka 567-0047
Japan

Telephone: 6-6879-8900
Facsimile: 6-6879-8899
E-mail: director@rcnp.osaka-u.ac.jp

University Institute

Ministry of Education, Culture, Sports, Science and Technology

Takashi Nakano

Head of the facility:
Takashi Nakano

Scientific Mission and Research Programs:

RCNP is a national research center for nuclear physics research both from the experimental and theoretical sides. The aim is to promote and perform world-level research in nuclear and particle physics using advanced accelerators and related facilities to answer basic questions such as “Why are quarks permanently confined in a nucleon?” and “how neutrons and protons constitute nucleus?” and “How was the universe born and formed?” The current major experimental activities are: (1) studies of static and dynamic properties of nuclei by using a high resolution proton and heavy-ion beams form the Ring Cyclotron, (2) studies of the quark and gluon properties in a nucleon by using a high-energy polarized photon beam at the Laser-Electron Photon facilities (LEPS and LEPS2) at SPring-8, and (3) studies on neutrinos and the dark matter of the universe at Kamioka Double Beta Decay Laboratory.

Technical facilities
Characterization of the facility:

Cyclotron complex (K140 AVF + K400 ring) with relatively light-ions (Figure on the left)

Laser-electron back-scattered photon facility (Figure on the right)

Table of facility parameters:

<table>
<thead>
<tr>
<th>particle</th>
<th>max. energy (MeV)</th>
<th>intensity (eμA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>400</td>
<td>1</td>
</tr>
<tr>
<td>d</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>3He</td>
<td>510</td>
<td>1</td>
</tr>
<tr>
<td>4He</td>
<td>400</td>
<td>1</td>
</tr>
<tr>
<td>Light-ions</td>
<td>100/A</td>
<td>1</td>
</tr>
</tbody>
</table>

High energy resolution with a dispersion matching method between the cyclotron and the magnetic spectrometer, ΔE/E is as good as 4x10^{-5}.

2. Polarized γ, 2.4 GeV, 2.5x10^6 cps
   Polarized γ, 3.0 GeV, 2.0x10^5 cps

Major experimental instrumentation and its capabilities:

Magnetic spectrometer “Grand Ralden”
   5.6 msr, δp/p = 5%, p/Δp = 37000

Large Acceptance Spectrometer Bρ = 3.2 Tm,
   20 msr, δp/p = 20%, p/Δp = 5000

Neutron TOF flight length = 100 m, Δt = 0.6 ns

Projectile fragment separator Bρ = 3.2 Tm,
   1.1 msr, δp/p = 8%, A/ΔA = 326

Nature of user facility:

National user facility (officially)

Number of actual, active users of the facility in a given year:

700 (last year)
NewSUBARU Synchrotron Light Facility
Kouto, Kamigor, Hyogo 678-1205
Telephone: +81-791-58-2543
Facsimile: +81-79-58-2504

Facility operated by
Laboratory of Advanced Science and Technology for Industry
University of Hyogo
Public University Corporation, Hyogo Prefecture, JAPAN

Shuji Miyamoto

Scientific Mission and Research Programs:

The aim of the facility of the low-energy γ-ray beam line is to contribute to the nuclear science by means of photon nuclear reactions. Gamma-ray beam is produced by laser Compton scattering (LCS) from the 0.5 GeV-1.5 GeV electron beam in the storage ring of NewSUBARU. A high intensity LCS photon beam is produced in the energy range of 0.5 MeV to 76 MeV.

The laser Compton scattering (LCS) gamma-ray beams are used in the fields of material science, beam physics, nuclear engineering, nuclear physics, and nuclear astrophysics. A new experimental hutch, GACKO (Gamma Collaboration Hutch of Konan University), was added in March 2012. LCS gamma-ray beams have been used in GACKO for positron production, energy calibration of electron beams, attenuation coefficient measurements, photo excitation of alpha-cluster states in nuclei, and nucleosynthesis study.

Technical facilities:

![Fig. 1 NewSUBARU synchrotron light facility. A electron beam at 1.0 GeV is injected into the storage ring with a top-up mode. The storage electron energies are 0.5 GeV to 1.5 GeV. Circumference of the storage ring is 118.73 m, accelerating RF frequency is 500 MHz and number of electron bucket is 198. Electron beam is injected from SPring-8 1 GeV linac.](image-url)
Fig. 2 Laser injection line, the collision part and for the experimental hutch of LCS-\(\gamma\).

Brief characterization of the facility:

MeV LCS \(\gamma\)-ray source in Synchrotron Light Facility

Table of facility parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam: (\gamma)-ray</td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>(10^6-10^9) /sec.</td>
</tr>
<tr>
<td>Energy range</td>
<td>0.5-76 MeV</td>
</tr>
<tr>
<td>Linear and circular polarization</td>
<td>&gt; 90%</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

- High resolution Ge detectors (45%)
- Nal scintillator
- Neutron detectors
- Gamma-ray flux meter

Nature of user facility:

- Collaborative use (80%)
- User facility (20%)

Fig. 3 LCS gamma-ray spectrum observed by a LYSO detector with a size of 50 mm in diameter and 90 mm in length. The photon beam is generated in the LCS process of Nd:YVO4 1 Watt laser light with a wavelength of 1064 nm from the 200 mA 1GeV electron beam. The maximum gamma-ray energy is 16.7 MeV. The photon intensity is \(2\times10^6\) \(\gamma\)/second.
Program Advisory Committee/experiment proposals?
Yes

Number of active users and their origin:
10 user groups

User group:
[1] JASRI (Japan Synchrotron Radiation Institute)
[2] RIKEN
[5] Research Center for Nuclear Physics, Osaka University
[6] Institute for Laser Technology
[7] Kyoto University
[8] Osaka Prefecture University
[9] Ecole Polytechnique LLR, France
[10] University of Saskatchewan, Canada

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
Permanent staff : 3
Temporary staff : 2

Number of theoretical staff employed at the facility:
No

Number of postdoctoral researchers:
1

Number of non-resident graduate students with thesis work primarily done at the facility:
about 10

Special student programs:
No

Future plans:
High power tunable infrared laser facility are expected to install for tunable LCS gamma-ray beam at NewSUBARU
JAEA and KEK group are planning to construct LCS gamma-ray beam facility for MeV γ-ray with an intensity of around $10^{13}$ photon/sec in the energy range of < 10 MeV in combination with the energy recovery linac (ERL) system at Tukuba.
OSAKA UNIVERSITY, VAN DE GRAAFF LABORATORY

1-1 Machikaneyama
Toyonaka, Osaka
560-0043, Japan
Telephone: +81-6-6850-5520
Facsimile: +81-6-6850-5535
E-mail: matsuta@vg.phys.sci.osaka-u.ac.jp

Faculty driven facility

Construction: Government
Operation: Government

Tadafumi Kishimoto

Head of the facility:
Kensaku Matsuta

Scientific Mission and Research Programs:
Scientific mission of the facility is to study nuclear physics and related fields, including nuclear structure, beta decay, and also solid state physics by use of nuclear technique. Main programs are the study of unstable nuclei through its nuclear moments, of the symmetry in the beta decay and of hyperfine interactions of beta emitting nuclei inside various kinds of materials. Any kinds of researches on nuclear physics and material sciences are welcome.

Characterization the facility:
Low energy electrostatic accelerator with light-ion beams (single-end Van de Graaff)

Facility Parameters:
beam species: p, d, ³He, ⁴He
Intensities: 30 μA
range of energies: 5 MeV (single charge) 10 MeV (double charge)
beam course: 4 (analyze d) 1 (strait)

Brief and compact table with the facility's major experimental instrumentation and its capabilities:
β-NMR apparatus
¹⁵N circulation target system for beta decay studies
Precision beta-ray correlation apparatus

Nature of user facility:
unofficially

Program Advisory Committee/experiment proposals
No

Technical facilities:
Number of actual, active users of the facility in a given year:

3 user groups (1 group from inside facility, 2 groups from outside)(average over about 20 years)

Percentage of users, and percentage of facility use:

Inside user is 40%, but the facility use is 80% from inside

Percentage of users and percentage of facility use from national users:

National user is 50%, but the facility use is only 10 % from national users

Percentage of users and percentage of facility use from outside the country where your facility is located:

International user is 10%, but the facility use is only 5 % from outside the country

Fraction of the international users is from outside your geographical region:

Almost zero

User Group:

No

Number of a) permanent staff and b) temporary staff:

a) presently, 3 faculty staff and 2 technician and 0.5 secretary
b) presently, 3 temporary staff (graduate students)

Number of postdoctoral researchers:

Presently none

Number of graduate students resident at the facility:

None

Number of non-resident graduate students with thesis work primarily done at the facility:

Presently 1

Involvement of undergraduate students in research:

Average is approximately 2

Special student programs:

1 student lab in summer for high school students
several times of open houses for high school students and public

Future Plans:

In the past, there was an upgrade plan to have small cyclotron, but presently none.
RIKEN NISHINA CENTER FOR ACCELERATOR-BASED SCIENCE

Asia (Saitama, Japan; North latitude: 35° 46’ 37”, East Longitude: 139° 37’ 11”)

2-1, Hirosawa
Wako, Saitama
351-0198, Japan
Telephone: +81-48-462-1111 (operator)
Facsimile: +81 48 461 5301
E-mail: enyo@riken.jp (Hideto En’yo, Director)
E-mail: kamigait@riken.jp (Osamu Kamigaito, Accelerator Division Head)
Email: UserSupportOffice@ribf.riken.jp (RIBF User Support Office)
http://www.nishina.riken.jp/RIBF/index.html

Independent Administrative Institution under the
Ministry of Education, Culture, Sports, Science and Technology

Dr. Ryoji Noyori (President)

Head of the facility:
Dr. Hideto En’yo (Director)

Scientific Mission and Research Programs:
RIKEN RI Beam Factory aims at providing exotic nuclei very far from stability as secondary beams for developing our understanding of nuclear structure and nuclear synthesis in the universe.

RI Beam Factory that was completed in 2006 started its full-scale operation in November 2008. The U and 48Ca beams are provided to nuclear physics experiments, which use rare isotopes as secondary beams produced and selected by using the fragment separator, BigRIPS. The primary beam energy is 345 MeV/u typically, and the beam current achieved so far is 15 pnA for U, 38 pnA for Xe, and 415 pnA for 48Ca, respectively. Additional primary beams, such as deuteron, He, N, O, Zn, and Kr can also be delivered.

Technical facilities:
Characterization of the facility:
Intermediate-energy cyclotron complex for heavy-ion involved science, including RI beam production.

Table of facility parameters:
Beam spices: from deuteron to $^{238}\text{U}$
Goal intensities: 1µA. 50 pnA for $^{238}\text{U}$ at 345 MeV/u will be achieved within the year 2017.
Range of energies: typically 345MeV/u using fRC
Special properties: A large acceptance fragment separator, BigRIPS, for secondary beam production.
Lower energy heavy-ion beams from 0.66MeV/u to 135MeV/u are also available. Details of available primary and secondary beam intensities can be found at the URLs of http://www.nishina.riken.jp/RIBF/accelerator/tecinfo.html, http://www.nishina.riken.jp/RIBF/BigRIPS/intensity.html.

Major experimental instrumentation and its capabilities:
Facilities in the low energy branch
- RIPS (RIKEN Projectile Fragment Separator)
- GARIS (Gas-filled recoil Separator for search for a super-heavy element)
- CRIB (Low energy secondary beam separator)

NEW facilities in operation
- Big-RIPS(Big RIKEN Projectile Fragment Separator)
- Zero Degree Spectrometer (ZDS)
- SAMURAI (Large Acceptance Spectrograph)
- SCRIT (Self Confining RI Target for electron scattering)
- SHARAQ(High Resolution Spectrograph)

New instrumentation under construction
- SLOWRI (RF Ion-Guided for slow and trapped RNB from a Projectile Fragmentation Separator)
- Rare-RI Ring

Nature of user facility:
RIBF is an user facility. RIBF User Support Office is the official contact for users.

Program Advisory Committee/experiment proposals:
Two scientific program advisory committees organized by worldwide experts exist, one for nuclear physics, NP-PAC, and the other for material and life science, ML-PAC.

Number of actual, active users of the facility in a given year:
476 (Number of users who attended the experiments at RIBF in Japanese fiscal year 2012)

Percentage of users, and percentage of facility use that come from inside the institution:
- Users: 46%
- Facility use (beam time): 71%

Percentage of users and percentage of facility use from national users:
- Users: 81%
- Facility use: 91%

Percentage of users and percentage of facility use from outside the country where your facility is located:
- Users: 19%
- Facility use: 9%

Fraction of the international users is from outside your geographical region:
Asia 21%, Europe 69%, North-America 7%, South America 2%, Africa 0%, Oceania 1%  
(from the user statistics of fiscal year 2012)

**User group:**
RIBF user’s group exists with 399 registerd members as of Septembr 2013. Details can be found at [http://ribfuser.riken.jp/RIBF_UG/](http://ribfuser.riken.jp/RIBF_UG/).

**Number of a) permanent staff and b) temporary staff (including graduate students and postdocs):**

a) (permanent) 75  
b) (temporary) 113

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**

Permanent : 7  
Postdoctoral : 12  
Graduate : 2

**Number of postdoctoral researchers:**

Facility : 20  
Others : 43

**Number of graduate students resident at the facility:**

68

**Number of non-resident graduate students with thesis work primarily done at the facility:**

43 (in the nuclear physics experiments since 2007)

**Involvement of undergraduate students in research (approximate average number per year):**

59

**Special student programs:**

1) Summer school is organized every summer by CNS, Univ. of Tokyo. at RIKEN Nishina Center. Graduate students and young postdocs from Asia, Europe and US are invited.  
2) Nuclear physics lecture series by distinguished nuclear physicists is organized for young researchers (about once a year).  
3) Nishina School is held every summer for Asian undergraduate students. This course includes a laboratory training course. Until present, Chinese ad Korean students are invited. We plan to expand the region in the future.

**Future Plans:**

The SLOWRI facility (RF Ion-Guided for slow and trapped RI from a Projectile Fragmentation Separator) in under construction.  
The primary beams from the IRC will become available in the low-energy branches.
KYUSHU UNIVERSITY TANDEM ACCELERATOR LABORATORY
(KUTL) FUKUOKA

Fukuoka, Western Japan

Tandem Laboratory
Department of Physics, Kyushu University
Hakozaki, Fukuoka, Japan 812-8581

Telephone & facsimilie: +81-642-2546
E-mail: sagara@nucl.phys.kyushu-u.ac.jp

Institute of Kyushu University
Japanese Government

S. Miyahara (Dean of Faculty of Science, Kyushu University)

Head of the facility:
Kenshi Sagara (Director of KUTL)

Scientific Mission and Research Programs:

a) Direct measurement of 12C+4He ->16O+ reaction cross section down to Ecm = 0.7 MeV. For this experiment, instruments and methods have been developed such as a blow-in windowless gas target (3kPa), a recoil mass separator, a chopper for recoils, transform of our tandem accelerator to a small tandem. The experiment will be finished in several years.

b) Anomalous cross section in three-nucleon break-up. Precise and systematic measurements of pd break-up at around 10 MeV have been in progress.

c) Accelerator mass spectrometry (AMS) for 14C.

Characterization of the facility:
A tandem accelerator with pulsed beam

Facility parameters:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Intensity</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>p,d</td>
<td>a few μA</td>
<td>2-18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MeV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C, O</td>
<td>5-0.1</td>
<td>3-60 MeV</td>
</tr>
<tr>
<td></td>
<td>particle μA</td>
<td></td>
</tr>
<tr>
<td>Si, Ni</td>
<td>50 particle nA</td>
<td>10-70 MeV</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recoil mass separator</td>
<td>ΔΩ = ±40 mr, E/q = 4 MeV, Δm/m = 200</td>
</tr>
<tr>
<td>Windowless gas target</td>
<td>He10 Torr x 3 cm, N2 30 Torr x 3 cm</td>
</tr>
<tr>
<td>Pulsed beam</td>
<td>3-6 MHz, width = 5-10 ns</td>
</tr>
<tr>
<td>Accel-decel operation</td>
<td>transform the 10 MV tandem to a 1 MV tandem</td>
</tr>
</tbody>
</table>
Technical facilities:

A recoil mass separator consisting of QQEMDDQQ (upper part) and a windowless gas target (lower part) for astro-nuclear experiments.

Nature of user facility:
Users can use the facility. Consult Director. K. Sagara (sagara@phys.kyushu-u.ac.jp)

Program Advisory Committee/experiment proposals:
Yes. Experiment proposals are discussed and scheduled in the weekly meeting.

Number of active users and their origin:
7 staff and 20 graduate students, 6 experimental groups

Percentage of users, and percentage of facility use that come from inside the institution:
Inside user 70%,
Inside use 85%

Percentage of users and percentage of facility use from national users:
100 %

Percentage of users and percentage of facility use from outside the country where your facility is located:
0% (foreign users are welcome)

Fraction of the international users is from outside your geographical region:
None

User group:
Yes. 7 staffs and 25 graduate students

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
a) 2, b) 0

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
0

Number of postdoctoral researchers:
1

Number of graduate students resident at the facility:
2

Number of non-resident graduate students with thesis work primarily done at the facility:
9

Involvement of undergraduate students in research:
5

Special student programs:
Lecture and experiment for undergraduates
Graduation thesis experiment for undergraduates
Learning experiment for high school students (2 days in a year)

Future plans:
New upgrade facility is under construction in a new campus. A FFAG synchrotron has been installed, and a small tandem accelerator will be installed. The present tandem accelerator will be shut down around 2013. We will report about our new facility in the next issue.

The present tandem accelerator was designed by A. Isoya in 1970’s. The accelerator and ion sources have been often improved for new experimental projects in collaboration with students. Many graduate students from our laboratory have gone to accelerator science and related fields.
TOKAI RESEARCH AND DEVELOPMENT CENTER, TANDEM FACILITY
JAPAN ATOMIC ENERGY AGENCY

Japan

Shirakata Shirane 2-4
Tokai, Ibaraki, 319-1195
JAPAN
Telephone: +81-29-282-5173
Facsimile:+81-29-282-6321
E-mail : osa.akihiko@jaea.go.jp

National Institute

Ministry of Education, Culture, Sports
Science and Technology

Shojiro Matsuura

Head of the facility:  
Akihiko Osa

Scientific Mission and Research Programs:  
Basic research in fields of nuclear physics, nuclear chemistry, and material science using accelerated heavy-ions.

(1) study of heavy-ion nuclear physics
(2) study of heavy-ion chemistry
(3) study of nuclear fuels and materials

Technical facilities:

Characterization of the facility:
(1) tandem accelerator and superconducting linac with heavy-ion beams

Table of facility parameters:
(1) tandem + superconducting linac

| beam species | proton to bismus |
**Brief and compact table with the facility's major experimental instrumentation and its capabilities:**

| Recoil mass separator | Ion-optical configuration: Q-Q-E-D-E-Q-E-Q-Q
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass resolving power: 300</td>
</tr>
<tr>
<td></td>
<td>Solid angle acceptance: 15 pi mm•mr</td>
</tr>
<tr>
<td></td>
<td>m/q acceptance ±4%</td>
</tr>
<tr>
<td></td>
<td>energy acceptance ±12%</td>
</tr>
</tbody>
</table>

| Isotope Separator On-Line (ISOL) | Ion-optical configuration: Q-Q-D
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass resolving power: 1200</td>
</tr>
<tr>
<td></td>
<td>Available ion-sources: surface and hot-plasma with $^{238}$U target</td>
</tr>
</tbody>
</table>

| Gamma-ray detector array (GEMINI-II) | Configuration: 20 Ge-detectors + Compton active shields |

**Nature of user facility:**
This facility is an official user facility by Japan Atomic Energy Agency (JAEA).

**Program Advisory Committee/experiment proposals:**
JAEA-PAC is for the proposals using heavy-ion beams.

**Number of actual, active users:**
151

**Percentage of users, and percentage of facility use that come from inside the institution:**
users: 72 %, facility: 28 %

**Percentage of users and percentage of facility use from national users:**
users: 90 %, facility: 98 %

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
users: 10%, facility: 2%

**Fraction of the international users is from outside your geographical region:**
Asia: 25%, North-America: 33%, Europe: 42%

**User Group:**
No

**Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):**
(a) permanent staff: 11, (b) temporary staff: 1

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**
permanent: 2, postdoctoral: 0, student: 0

**Number of postdoctoral researchers:**
2

**Number of graduate students resident at the facility:**
2

**Number of non-resident graduate students with thesis work primarily done at the facility:**
6

**Involvement of undergraduate students in research (approximate average number at a given time):**
0

**Special student programs:**
There exist a summer program for undergraduate student.

**Future Plans:**
Irradiation Room No. 2 will be operated as a treatment area of unsealed radioactive materials for study with actinide targets.
UNIVERSITY OF TSUKUBA
TANDEM ACCELERATOR COMPLEX

Tsukuba, Japan
Tennoudai 1-1-1
Tsukuba
Ibaraki, 305-8577
Japan
Telephone: +81-29-853-2490
Fascimile: +81-29-853-2565
Email: nagashima@tac.tsukuba.ac.jp

University Facility

Head of the facility:
Yasuo Nagashima

Scientific Mission Research Programs:

Technical facilities:

Characterization of the facility:
Electrostatic accelerator facility with two tandems

Facility Parameters:
H,D,Polarized H,Polarized D,He,B,C,O,Cl,Au,Bi
(Many species)
0.5MeV----150MeV(Depend on the species)

Brief and compact table with the facility's major experimental instrumentation and its capabilities:
Accelerator Mass Spectrometry System (AMS),
Micro Beam Hydrogen Analysis System (ERCS),
Micro Beam PIXE (µ-PIXE), Recoil Back Scattering Particle Analysis System (RBS),
Momentum Analyzer (ESP-90), Polarized Ion Source

Nature of user facility:
Yes

Program Advisory Committee/experiment proposals:
Yes

Number of actual, active users of the facility in a given year:
60

Percentage of users, and percentage of facility use that come from inside the institution:
Percentage of users; 90%
Percentage of facility use; 70%

Percentage of users and percentage of facility use from national users:
Percentage of users; 99%
Percentage of facility use; 98%

Percentage of users and percentage of facility use from outside the country where your facility is located:
Percentage of users; 1%
Percentage of facility use; 2%

Fraction of the international users is from outside your geographical region:
Asia; 100%

User Group:
Yes, total number of registered members are 120.
Number of a) permanent staff and b) temporary staff:

a) permanent staff; 13
b) temporary staff; 8

Number of postdoctoral researchers:
1

Number of graduate students resident at the facility:
7

Number of non-resident graduate students with thesis work primarily done at the facility:
3

Involvement of undergraduate students in research:

Special student programs:
Student labs for high school students
Experiments with the accelerator for undergraduate students
Scientific Mission and Research Programs:
CYRIC was established in 1977 as an institution for carrying out research studies in various fields with the cyclotron and radioisotopes, and for training researchers of Tohoku University for safe treatment of radioisotopes and radiations.

In conformity with the aim of establishment of CYRIC, the cyclotron has been used for studies in various fields of research, such as nuclear physics, nuclear chemistry, solid-state physics and element analysis by PIXE and activation, and for radioisotope production for use in engineering, biology and medicine.

Technical facilities:
From 2001, two cyclotrons are working; the first is the new cyclotron (K=110 MeV) which is replaced from the old one (K=50 MeV) for light ion beam and the second is the small cyclotron (12 MeV proton) for the production of positron emitters of PET study.

Overview of facility (two cyclotrons and 6 experimental halls)

Characterization of the facility:
Low-energy cyclotron with light-ion beams

Technical facilities:
Facility Parameters:
Beam energies of the new AVF cyclotron (K=110 MeV) and small cyclotron for PET.

a) Positive ion acceleration by K=110 cyclotron

<table>
<thead>
<tr>
<th>Accelerated</th>
<th>Particle (MeV)</th>
<th>Energy</th>
<th>Beam intensity (uA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>10-90</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>10-65</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>He3</td>
<td>20-170</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>He4</td>
<td>20-130</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

b) Negative ion acceleration by K=110 MeV cyclotron.
<table>
<thead>
<tr>
<th>Accelerated Particle Energy (MeV)</th>
<th>Beam intensity (uA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>10 - 50</td>
</tr>
<tr>
<td>d</td>
<td>10 - 25</td>
</tr>
<tr>
<td>p</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
</tr>
</tbody>
</table>

c) Negative ion acceleration by small cyclotron for PET

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

- Beam Swinger and Large Solid-angle Neutron Detection system for Time-of-Flight Experiments
- On-line Electric and Magnetic Isotope-separator
  - High-energy g-ray Detection System
  - Laser cooled and trapped RI source
- High Intensity Thermal and Epi-thermal Neutron Source
- Medical developments of new PET medicines and cancer therapy by proton beam

Nature of user facility:
The facility is officially opened for inside-users of university, but is not closed for outside-users’ proposals.

Program Advisory Committee/experiment proposals:
Yes.

Percentage of users, and percentage of facility use that come from inside the institution:
- 20%: users from institute
- 50%: users from Tohoku University
- 30%: users from outside university

Percentage of users and percentage of facility use from national users:
- 95 %

Percentage of users and percentage of facility use from outside the country where your facility is located:
- 5%

Fraction of the international users is from outside your geographical region:
- Asia and Europe

User group:
- 20 groups

Number of a) permanent staff and b) temporary staff:
- a) permanent: 9 researchers and 4 technical members
- b) temporary: 26 including graduate students

Number of postdoctoral researchers:
- Three

Number of graduate students resident at the facility:
- 25 students in this year (physics, engineering and medical course)

Number of non-resident graduate students with thesis work primarily done at the facility:
- 1-3 students in every year

Involvement of undergraduate students in research:
- 10 students at last year

Special student programs:
Lectures and site-seeing for high school students and citizens at every summer time (2 days)

Future Plans:
- a) Nuclear structure study by intense unstable nuclei and beams
- b) Development of intense high energy neutron beams by upgrade of AVF cyclotron and negative ion acceleration and the engineering and medical applications (BNCT) by the neutron beam
- c) Fundamental researches for cancer therapy by proton beam
Scientific Mission and Research Programs:
Research Center for Electron-Photon Science (ELPH) is a nationwide joint-use research center in electron-photon science. It was founded to aim at carrying out fundamental researches and applications in nuclear science, and educating students in related fields. ELPH operates two accelerators (Fig. 1): a 60 MeV electron linear accelerator and a 1.3 GeV electron booster synchrotron.

Technical facilities:
The accelerator facilities were severely damaged by the Great East Japan Earthquake occurred in March 11, 2011. After a long-term recovery work, the accelerators were restored, partially renewed, and started operation in the end of 2013.

The linear accelerator provides an intense pulsed beam and has been used in a wide range of research fields, not only nuclear physis but solid state physics, radiochemistry, biology and so on. The 1.3 GeV synchrotron provides two GeV tagged photon beams using internal radiators for quark nuclear physics researches.

Fig.1 ELPH Accelerator Facilities
Characterization of the facility:
60 MeV High Intensity Linac
to provide an intense electron beam
1.3 GeV Booster Electron Synchrotron
to produce GeV tagged photon beams

Facility Parameters:
Beam :
1) an electron beam
2) (tagged) photon beams
3) a positron beam
Energy and intensity :
1) e− (and bremsstrahlung)  
   60 MeV, 180 µA (max), 300 pps
2) tagged photon beams :
   0.6 – 1.2 GeV, 3 x 10^7 /sec
3) e+ : 100 – 850 MeV, 1 kHz – 1 MHz

Brief and compact table with the facility's major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Lab. Tohoku U.</th>
<th>Tohoku U. national</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quark Nuclear Physics</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Nuclear Physics</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Science Beam Physics</td>
<td>70</td>
<td>0</td>
</tr>
</tbody>
</table>

User group:
Yes. About 150.

Number of a) permanent staff and b) temporary staff:
a) 9 scientists and 5 technical staffs
b) 5 temporary staff

Number of postdoctoral researchers:
0

Number of graduate students resident at the facility:
11

Number of non-resident graduate students with thesis work primarily done at the facility:
2

Special student programs:
nothing

Future Plans:
1) Accelerator: construct Supercoherent Terahertz Photon Ring.
2) Quark Nuclear Physics: construct a new photon beam line at SPring8 (joint work with RCNP and Spring-8).
3) Nuclear physics: construction of a world’s first electron scattering facility dedicated for structure studies of short-lived nuclei (joint work with RIKEN RIBF).
HEADS OF THE FACILITIES:

Jae-Gahb Park, M.D., Ph.D
Kwan-Ho Cho, MD

SCIENTIFIC MISSION AND RESEARCH PROGRAMS:

The experimental area of the proton therapy facility will be used to perform radiation damage measurements such as for semiconductor and biological objects. The area will also be used to develop the devices for advanced radiation treatments and to test the detector parts to ensure their expected performances. The Research Institute of National Cancer Center will have around 140 staff members composed of mainly biologist and medical doctors for the developments of diagnostics, prevention and treatments of cancer.

TECHNICAL FACILITIES:
Characterization of the facility:
Intermediate energy cyclotron, low-energy electron linacs for therapy

Facility Parameters:
Proton, 0.1-300 nA, 50-230 MeV

Major experimental instrumentation and its capabilities:
Nozzles to form large-area uniform beams.

Nature of user facility:
Therapy facility,
Expected users: nuclear, medical physicists and radiation biologists

Program Advisory Committee/ experiment proposals:
Not formed yet.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 3 PhD and 5 MD, b) 4 PhD and 3 MD

Number of postdoctoral researchers:
four

Number of non-resident graduate students with thesis work primarily done at the facility:
two

Future Plans:
Facility will have beams in the end of 2005, and plan to begin treating patients in 2006.
The experimental area is expected to be prepared in 2006.
KOREA INSTITUTE OF GEOSCIENCE AND MINERAL RESOURCES
(WWW.KIGAM.RE.KR)
ION BEAM APPLICATION GROUP (IONBEAM.KIGAM.RE.KR) WITH A MULTI-
PURPOSE ION BEAM ACCELERATOR

Daejeon, Republic of Korea (South Korea)

30 Kajeong-dong
Yuseong-ku
Daejeon, Korea
Telephone: +82-42-868-3666
Facsimile: +82-42-868-3393
E-mail: whong@rock25t.kigam.re.kr

An institute base on national funding

Government
Government, Companies

Head of the facility:
Dr. Tae Sup Lee
Dr. Hyung Joo Woo

Scientific Mission and Research Programs:
Most applications of middle size (1.7 MV tandem) ion beam accelerator have been performed at this facility. Main application is ion beam analyses such as ERD-TOF, RBS/channeling, PIXE/PIGE, and NRA. The other application is high energy ion beam implantation for surface modification of semiconductor devices. Studies on ion beam engineering such as ion beam lithography, ion beam MEMS, nano-crystal forming, and SOI (Si on Insulator) wafer fabrication are also done. And this facility is used for neutron capture cross-section measurement of nuclear physics field. An AMS system will be introduced next year (2006), of which main purpose will be global environmental change study.

Technical facilities:
Characterization of the facility:

medium-energy (TV=1.7 MV) tandem accelerator with heavy-ion sources

**Facility Parameters:**

<table>
<thead>
<tr>
<th>Negative Ion</th>
<th>Beam Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injector Faraday Cup</td>
</tr>
<tr>
<td>H</td>
<td>-13.0 ~ -15.0 ( \mu A )</td>
</tr>
<tr>
<td>D</td>
<td>-6.5 ~ -12.5 ( \mu A )</td>
</tr>
<tr>
<td>B</td>
<td>~ -1.4 ( \mu A )</td>
</tr>
<tr>
<td>C</td>
<td>-14.0 ~ -20.8 ( \mu A )</td>
</tr>
<tr>
<td>O(ZnO)</td>
<td>-24.5 ~ -35.0 ( \mu A )</td>
</tr>
<tr>
<td>F</td>
<td>-11.1 ~ -20.6 ( \mu A )</td>
</tr>
<tr>
<td>Si</td>
<td>-20.0 ~ -33.0 ( \mu A )</td>
</tr>
<tr>
<td>P</td>
<td>-8.3 ~ -10.18 ( \mu A )</td>
</tr>
</tbody>
</table>

*Total acceleration = 28 kV (pre-acceleration) + terminal voltage \times (charge state + 1)*

**Major experimental instrumentation and its capabilities:**

Cesium sputtering source (NEC)

RF source (NEC)

Analysis chamber with 6-axis goniometer sample stage

Implantation chamber with temperature controller and precise beam current monitor

Mono-energetic neutron beam generation facility

Particle detectors (charged particles and neutrons)

Photon detectors (gamma-ray and X-ray)

Electronics for measurement

Nature of user facility:
Yes (officially)

Program Advisory Committee/experiment proposals:
Yes

Number of actual, active users of the facility in a given year:
Simple analysis service: 256 users in 2004 (more than 1,000 samples)
Visiting users for experiment: 2 users in 2004

Percentage of users, and percentage of facility use that come from inside the institution:
All users came from outside of our institute

Percentage of users and percentage of facility use from national users:
See the answer of next question

Percentage of users and percentage of facility use from outside the country where your facility is located:
One user came from outside Korea

Fraction of the international users outside of geographical region:
None

User Group:
None

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
5 staffs (plan to hire one more staff in this year)
1 staffs (plan to hire 3 more staffs in this year)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
None

Number of postdoctoral researchers:
None

Number of graduate students resident at the facility:
None

Number of non-resident graduate students with thesis work primarily done at the facility:
None now

Involvement of undergraduate students in research (approximate average number per year):
None now

Future Plans:
The project to introduce an AMS system started this year
NATIONAL CENTER FOR INTER-UNIVERSITIES RESEARCH FACILITY / ELECTROSTATIC ION ACCELERATOR ACCELERATOR MASS SPECTROSCOPY DIVISION

Seoul, Korea

NCIRF Bldg. 139
Seoul National University
Seoul 151-742, Korea
Administration Telephone: +82-2-880-5431
Administration Facsimile: +82-2-884-6661
Lab. Telephone: +82-2-880-5774
Lab. Facsimile: +82-2-880-5781
Corresponding E-mail: myoun63@snu.ac.kr

National Institute established under Korean law, maintained as a part of University organization

Construction: Ministry of Education, ROK (100%)
Operation: Ministry of Education, ROK (~40%)
University Budget (~60%)

Heads of the facility:
Prof. SeungWhan Hong
Prof. Jong Chan Kim

Scientific Mission and Research Programs:
The institution technically supports for researches concerning natural science, engineering, and literature providing user facilities and highly reliable analysis services. The electrostatic accelerator facility provides ion beam based upon user request, and services AMS analysis as well as radiocarbon dating. The scientific staffs and technical staffs also pursue the facility’s own research program.

Technical facilities:
Characterization of the facility:
Low energy tandemron with light-ion beams (heavy-ion beam will be provided based upon R&D).

Facility Parameters:

<table>
<thead>
<tr>
<th>Beam species</th>
<th>intensity</th>
<th>Range of Energy</th>
<th>Special feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H, 2H</td>
<td>200nA Max</td>
<td>1–6 MeV</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>100nA Max</td>
<td>1–10 MeV</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Typically 150nA</td>
<td>2–10 MeV</td>
<td>12C, 13C, 14C recombinator</td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:
1. Duoplasmatron ion source
2. Cs-sputtering ion source (1 dedicated for C-beam) beam recombinator
   - Spectrometer
   - Gamma detectors, charged particle detectors
   - PIXE beamline
   - Heavy-isotopes AMS beamline (under construction)

Nature of user facility:
Officially a user facility (by law). No other unofficial, practical aspects.

Program Advisory Committee/experiment proposals:
Yes.

Number of actual, active users of the facility in a given year:
As an ion-beam user facility; Seoul National University
For the analysis service; Over 500 users per year

Percentage of users, and percentage of facility use that come from inside the institution:

<table>
<thead>
<tr>
<th></th>
<th>Inside SNU</th>
<th>Outside SNU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion beam</td>
<td>75%</td>
<td>25%</td>
</tr>
<tr>
<td>AMS analysis</td>
<td>12%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Percentage of users and percentage of facility use from national users:

<table>
<thead>
<tr>
<th></th>
<th>Domestic</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion beam</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>AMS analysis</td>
<td>45%</td>
<td>55%</td>
</tr>
</tbody>
</table>

Percentage of users and percentage of facility use from outside the country where your facility is located:
See above

Fraction of international users outside of geographical region:
No statistics available

User Group:
None

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
4 scientific staff, 4 technical staff
2 graduate students, 1 post-doc.

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
None

Number of postdoctoral researchers:
One

Number of graduate students resident at the facility:
One

Number of non-resident graduate students with thesis work primarily done at the facility:
One

Involvement of undergraduate students in research (approximate average number per year):
None

Special student programs:
None

Future Plans:
beamlines construction: to extend the experiments that use ion beam
AMS development
Theoretical nuclear physics
ANU HEAVY ION ACCELERATOR FACILITY

Australian National University Campus
Canberra, Australia

Department of Nuclear Physics
R.S.P.E.
Australian National University
Canberra, A.C.T. 0200
Australia

Telephone: +61-2-6125 2083
Facsimile: +61-2-6125 0748
E-mail: nuclear@rsphysse.anu.edu.au
Facility Head: David.Hinde@anu.edu.au
Web address : www.rsphysse.anu.edu.au/nuclear

University Institute

Various sources of funding:
Initial Establishment: University Funds and Direct Commonwealth Government Grant
Staffing and Operation: Internal University Funds
Instrumentation and development: Internal University Funds and Competitive External Grants, including the
Australian Research Council

Heads of the facility:

Facility is operated by the Department of Nuclear Physics;
Head: Professor David Hinde
Facility Director: Professor Keith Fifield
Facility Operations Manager: Dr Nikolai Lobanov

Scientific Mission and Research Programs:
The mission of the Facility is to carry out internationally competitive research in both basic areas of Nuclear Physics and selected applications, to maintain and develop accelerator capabilities for the research community, and to provide a training ground for postgraduate and postdoctoral research in nuclear physics and related areas.

The current research programme encompasses

• Fusion and Fission Dynamics with Heavy Ions
• Nuclear Spectroscopy and Nuclear Structure
• Nuclear Reaction Studies
• Nuclear Moments and Hyperfine Fields
• Perturbed Angular Correlations and Hyperfine Interactions Applied to Materials
• Heavy Ion Techniques for Materials Stoichiometry
• Accelerator Mass Spectrometry – Development and application
Technical facilities:

Aerial view of the Heavy Ion Accelerator Facility within the laboratories of the Research School of Physical Sciences and Engineering

ANU Heavy Ion Accelerator Facility: General Layout
Characterization of the facility:

Electrostatic Tandem accelerator operating in the 15MV region with the ability to inject into a modular superconducting Linear Accelerator. Producing a broad range of heavy ion beams delivered to ten experimental stations, instrumented for a range of national and international users. Pulsed and chopped beams; Gas and foil stripping and double-stripping operation for heavy beams.

Facility Parameters:

A broad range of beam species is available, with LINAC beams under development. Beam intensities vary with beam species, from a few particle-nanoamps of the heaviest beams to 100 particle-nanoamps for lighter beams such as $^{12}$C and $^{16}$O. Flexible, pulsed-beam conditions ranging from nanosecond pulsing to macroscopic chopping in the millisecond and seconds region.

<table>
<thead>
<tr>
<th>Beam Species</th>
<th>Max Energy Single Stripping (MeV)</th>
<th>Max Energy Double Stripping (MeV)</th>
<th>Max Energy LINAC (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{6,7}$Li</td>
<td>60</td>
<td></td>
<td>84</td>
</tr>
<tr>
<td>$^{9}$Be</td>
<td>75</td>
<td></td>
<td>107</td>
</tr>
<tr>
<td>$^{10,11}$B</td>
<td>90</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>$^{12,13}$C</td>
<td>105</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>$^{16,17,18}$O</td>
<td>120</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td>$^{24,25,26}$Mg</td>
<td>150</td>
<td>170</td>
<td>211</td>
</tr>
<tr>
<td>$^{27}$Al</td>
<td>150</td>
<td>180</td>
<td>230</td>
</tr>
<tr>
<td>$^{28,29,30}$Si</td>
<td>165</td>
<td>185</td>
<td>235</td>
</tr>
<tr>
<td>$^{31}$P</td>
<td>165</td>
<td>195</td>
<td>267</td>
</tr>
<tr>
<td>$^{32,34}$S</td>
<td>165</td>
<td>195</td>
<td>278</td>
</tr>
<tr>
<td>$^{35,37}$Cl</td>
<td>180</td>
<td>204</td>
<td>294</td>
</tr>
<tr>
<td>$^{40}$Ca</td>
<td>180</td>
<td>229</td>
<td>320</td>
</tr>
<tr>
<td>$^{58,64}$Ni</td>
<td>195</td>
<td>259</td>
<td>360</td>
</tr>
<tr>
<td>$^{74}$Ge</td>
<td>195</td>
<td>259</td>
<td>409</td>
</tr>
<tr>
<td>$^{81}$Br</td>
<td>195</td>
<td>269</td>
<td>427</td>
</tr>
<tr>
<td>$^{127}$I</td>
<td>210</td>
<td>304</td>
<td></td>
</tr>
<tr>
<td>$^{197}$Au</td>
<td>210</td>
<td>323</td>
<td></td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Capability</th>
<th>Research Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAESAR Gamma-Ray Array</strong></td>
<td>Nine Compton-suppressed Ge and two LEPS Detectors; Various ancillary devices.</td>
<td>Nuclear Structure; Time-correlated gamma-ray spectroscopy</td>
</tr>
<tr>
<td><strong>SOLENO-GAM: Gamma-ray and electron spectrometer module behind SOLITAIRE separator</strong></td>
<td>Transport of residues to focal Plane instrumented with high-resolution electron and gamma detectors</td>
<td>Nuclear structure; characterisation of isomeric states in neutron-deficient nuclei.</td>
</tr>
<tr>
<td><strong>HYPERION</strong></td>
<td>Gamma-ray correlation table with cryogenic system for sample cooling</td>
<td>Nuclear structure and Hyperfine interaction applications</td>
</tr>
<tr>
<td><strong>Two-metre Scattering Chamber</strong></td>
<td>Hybrid detectors for broad-range particle identification</td>
<td>General applications including elastic recoil Detection analysis (ERDA)</td>
</tr>
<tr>
<td><strong>CUBE Spectrometer; BALIN breakup array</strong></td>
<td>Large area position-sensitive multi-wire proportional detectors. Si-strip detector array.</td>
<td>Heavy Ion Reaction dynamics; fission, fusion, breakup and incomplete fusion.</td>
</tr>
</tbody>
</table>
The five-year average for the period 2003-2008 inclusive was about 80 per year.

*This does not include numerous collaborators who are not able to travel to the facility for on-site running of experiments.*

**Percentage of users, and percentage of facility use that come from inside the institution:**
(2003-2008 Period): 36%

**Percentage of users and percentage of facility use from national users:**
(2003-2008 Period): 18%

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
(2003-2008 Period): 46%

**Fraction of international users outside of geographical region**
(2003-2008 Period): 80%

**User Group:**
A Web registration system is being implemented.

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**

a) Permanent Staff; Total of 19, composed of 7 Academic staff, 2 Scientific Staff at PhD level and 10 General/Technical Staff.

b) Short term Staff: Approximately 25 (Postdoctoral/student/Visiting Fellows).

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**
Permanent – currently none
Short-term – typically one or two.

**Number of postdoctoral researchers:**
On average 10

**Number of graduate students resident at the facility:**
Approximately 10

**Number of non-resident graduate students with thesis work primarily done at the facility:**
Approximately 10
Involvement of undergraduate students in research (approximate average number at a given time):
Approximately 10

Special student programs:
Annual workshops in Radiation Physics, Applications of Accelerators – duration approximately 1 week each with involvement of about 20-30 undergraduate students, mainly from other Universities.

Annual involvement in summer scholar programs (10-week projects), Industry youth schemes (CSIRO etc.) and Honours undergraduate programs (6-month projects) and various National Youth summer schools.

Master of Nuclear Science Program (coursework) instituted in January 2007.

Future Plans:
Mainly incremental upgrades of detector instrumentation (for example, recoil spectrometer for spectroscopy studies).

Recent accelerator improvements funded through the Australian Research Council for include additional Computer Control, improved beam intensities (ion source and pulsing efficiencies) and upgrading of LINAC resonator RF systems and control. AMS facilities have been extended with a dedicated Radio Carbon accelerator system (sited in the Research School of Earth Sciences, commissioned in late 2007).

Almost completed is the compact radioactive ion-beam facility SOLEROO designed around a 6.5T superconducting solenoid with active beam tracking and particle identification. The initial aim is production of a tagged He-6 beam using Li-7 induced reactions on Be-9.
Contact Person for Foreign Users
Carmen Angulo
Telephone: +32 10 47 32 31
E-mail: angulo@cyc.ucl.ac.be
Carine Baras
Telephone: +32 10 47 29 98
E-mail: baras@cyc.ucl.ac.be

Facility:
Cyclotron CYCLONE110 for ions from H (25 µA, 10–90 MeV) to Xe (few nA, 400 MeV), including 5–25 MeV/µ ¹²C to ⁴⁰Ar ions and 0.65–10 MeV/µ radioactive ions.
Cyclotron CYCLONE30 for H beams up to 30 MeV, 500 µA.

Procedure to Apply for Beamtime:
Send a written proposal to the secretary of the PAC (C. Angulo). Present it orally (twice per year, beginning of January and beginning of July).

Programme Advisory Committee (current membership):
1 in-house, 3 national, 5 international members.

Main Instrumentation for Nuclear Physics Experiments:
Radioactive ion beam facility for ⁶He, ⁷Be, ¹⁰C, ¹¹C, ¹³N, ¹⁵O, ¹⁸Ne, ¹⁹Ne, ³⁵Ar (other radioactive beams under development) using CYCLONE110 with CYCLONE30. Leuven Isotope Separator On-Line (LISOL) with FEBIAD, ion guide (LIGISOL) and laser ion sources.
Monoenergetic fast neutron facility (20-75 MeV). Electron cyclotron resonance ion sources.
Neutron multidetector array (DEMON).
Multistrip charged particle detectors (LEDA).

Main Fields of Nuclear Research:
Nuclear astrophysics in explosive environments.
Exotic light nuclei and nuclei far from stability.
Heavy ion reaction mechanisms.
Fast neutron interactions of interest for biology and energy generation.

Main Fields of Other Research:
Radiobiology, neutron dosimetry.
Nuclear chemistry.
Radiation damage by light, heavy and fast neutrons.
Detector calibration for space missions.

Accommodation:
2 apartments in the immediate neighborhood, 2 hotels within walking distance.

Transportation:
Public transportation from the center of Brussels and from Brussels National Airport by fast connection.
NUCLEAR PHYSICS INSTITUTE

Řež near Prague (Czech Republic)

Academy of Sciences of the Czech Republic
CZ-250 68 Řež
Czech Republic
Facsimile: +420 220941130
WWW: http://www.ujf.cas.cz/

J. Dobeš, Director
Telephone: +420 220941147
Facsimile: +420 220941130
E-mail: dobes@ujf.cas.cz

Contact Person for Foreign Users
J. Štursa
Telephone: +420 266173613
Facsimile: +420 220941130
E-mail: stursa@ujf.cas.cz

Scientific Mission and Research Programs:
Nuclear astrophysics, fast neutron benchmark tests of activation cross sections, neutronic tests of fusion related materials, cross section measurements and preparation of new radionuclides for nuclear medicine purposes.

Characterization of the facility:
Cyclotron U-120M: Isochronous cyclotron (K=40) for light ions operated in both positive (p, D, 3He2+, 4He2+) and negative (H−, D−) regimes.

Major experimental instrumentation and its capabilities:
Achromatic magneto-optical system for spectroscopy of nuclear reaction products.
High-power-wide spectrum fast neutron sources ($10^{11}$ n/s/cm² up to 32MeV).
Scintillator detector based fast neutron spectrometer.

Main Fields of Nuclear Research:
Nuclear Astrophysics.
Fast neutron benchmark tests of activation cross sections.

Main Fields of Other Research:
Neutronic tests of fusion related materials.
Cross section measurements and preparation of new radionuclides for nuclear medicine purposes.

Accommodation:
Institute guest rooms on the site.
Hotel within walking distance from the Institute.

Transportation:
The Institute is located 20km from Prague.
Trains and buses go from and to Prague every 1 hour from 5 am to 12 pm.

Future Developments (under construction):
New beam lines dedicated to particular projects.
Increase of external beam intensity up to 50mA.
ACCELERATOR LABORATORY
UNIVERSITY OF JYVÄSKYLÄ

Department of Physics
University of Jyväskylä
Jyväskylä, Finland

Department of Physics
P.O. Box 35 (YFL)
FI-40014 UNIVERSITY OF JYVÄSKYLÄ
Finland

Telephone: +358 505919526
E-mail: rauno.julin@jyu.fi

University Institute
Various sources of funding:
State budget of Finland
University of Jyväskylä, Academy of Finland, European Union Programmes

Heads of the facility: Professor Rauno Julin

Scientific Mission and Research Programs:
The Accelerator Laboratory at the University of Jyväskylä (JYFL) is a national facility with an extensive international programme in education and research on atomic nuclei under extreme conditions as well as related applications.
The current research activities include:

Decay and ground-state properties of exotic nuclei
Weak interaction physics
Structure and spectroscopy of superheavy elements
Structure and spectroscopy of proton-drip line nuclei
Accelerator-based materials physics
Radiation testing for the space industry

Technical facilities:

Figure 2: View of the Department of Physics at the Ylistö campus area.
Figure 1: Layout of the upgraded JYFL Accelerator Laboratory.

Characterization of the facility:
The accelerator facility consists of three accelerators:
A K=130 AVF cyclotron equipped with two ECR ion sources for heavy ions and a multi-cusp ion source for protons, a K=30 negative ion cyclotron for protons and deuterons and a 1.7 MV Pelletron accelerator.
Reliability of the K=130 MeV cyclotron is reflected in the annual operation time of more than 6000 hours. As the maximum energy for the ion beam from the cyclotron is \( E/A = 130(q/A)^2 \) MeV/n, the availability of various beams strongly depends on the performance of the ion sources. Heavy ions are delivered by a 6.4 GHz or a 14 GHz ECR ion source.
The K=30 MeV cyclotron accelerates 18 – 30 MeV protons and 9 – 15 MeV deuterons. It has two beam lines to opposite directions: one for the IGISOL facility and one for applications (e.g. isotope production).
The Pelletron accelerator delivers low-energy protons and He ions for ion-beam applications.

Facility parameters:
Available beams and intensities from the cyclotron for ions with energies above 5 MeV per nucleon are as follows:
- \( > 1 \mu A \)
- \( p, He, B, C, N, O, Ar \)
- \( > 100 \) pnA
- \( F, Ne, Mg, Al, Si, S, Cl, Ca, Fe, Cr, Ni, Cu, Zn, Kr \)
- \( > 10 \) pnA
- \( Ti, Mn, Ge, Sr, Zr, Ru, Xe \)

Intensities for various isotopes depend on the isotopic enrichment of the available material. Metallic beams are extracted from a furnace or a MIVOC chamber. The MIVOC method (based on the use of volatile compound) was developed at JYFL. Negative H ions for high-intensity proton beams up to 50 µA from the cyclotron are produced in the multi-cusp source.

Major experimental instrumentation and its capabilities:
Online isotope separator IGISOL can separate nuclei far from stability, especially those of refractory elements not available elsewhere.
Penning Trap JYFLTRAP consists of a Radiofrequency Quadrupole (RFQ) beam-cooler device and a high-precision Penning trap. It has been used to measure masses of around 200 nuclei with high accuracy.

Laser Ion Source FURIOUS currently under development to provide enhanced beam intensity and purity for exotic nuclei from IGISOL

Collinear Laser Spectroscopy Line allows high-sensitivity laser spectroscopy measurements of all elements, using cooled and bunched beams from IGISOL

Gas-filled Recoil Separator RITU is one of the leading instruments in the world for studies of neutron-deficient heavy nuclei.

Focal Plane Spectrometer GREAT developed by a group of U.K. institutes and located at the focal plane of RITU. Allows detailed measurement of the decay properties of implanted ions.

Vacuum-mode Revoil Separator MARA is under construction. It will enable tagging studies of light proton-rich nuclei near the N=Z line.

Germanium Detector Array JUROGAM2 consists of 24 Compton suppressed Clover- and 15 EUROGAM Phase 1 Ge detectors (efficiency 6% @ 1.3 MeV) and is used in conjunction with RITU in Recoil-Decay Tagging studies.

Large Scattering Chamber LSC is used in Nuclear Reaction studies and Stopping Power measurements.

Radiation Effects Facility RADEF is used to study radiation effects in materials and electronics components (mainly for the space industry in collaboration with ESA)

Beam lines equipped with PIXE, RBS, ToF-ERDA and litography instruments for applied research at Pelletron

Nature of facility:
The JYFL Accelerator Laboratory is considered a user facility. It is one of the EU-IA-ENSAR Access Facilities.

Program Advisory Committee/experiment proposals:
The research program at JYFL is overseen by the Program Advisory Committee, consisting of six external members, three local members and a scientific secretary. There are two calls for proposals each year with deadlines of March 15th and September 15th.

Percentage of users and percentage of facility use from outside the country where your facility is located:
Approximately 80% and 70%, respectively. The number of foreign users during the last 5 years has been on the average 200 per year.

Percentage of users, and percentage of facility use that come from inside the institution:
Approximately 15% of the users and 30% of the facility use are from inside the institution.

Percentage of users and percentage of facility use from national users:
Approximately 5%

Fraction of international users outside of geographical region:
Those outside Europa approximately 10%.

User Group:
The JYFL Accelerator Laboratory does not have a formal users group, but regularly organizes users meetings and workshops to discuss the status and future of research in the laboratory.

Number of a) total laboratory staff (all categories) b) scientists on staff with doctoral degree:
a) 62 in total b) 21 scientists with doctoral degree (13 senior researchers, 8 post-doc researchers, 28 PhD students, 13 lab. engineers and technicians)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
There are 7 theoretical staff employed at the facility, of which 1 is permanent, 2 are postdoctoral and 4 are graduate students.

**Number of postdoctoral researchers:**
There are 8 postdoctoral staff employed.

**Number of graduate students resident at the facility:**
There are 28 graduate students resident at the facility.

**Number of non-resident graduate students with thesis work primarily done at the facility:**
Around 25 nonresident graduate students whose thesis work is done primarily at the facility.

**Involvement of undergraduate students in research (approximate average number per year):**
At any given time, there are approximately 10 undergraduate students working in research at the facility.

**Future Plans:**
Commissioning of the new K30 MeV cyclotron will release beam time for tests and long experiments and applications. To hold on to the status as a leading Stable Ion Beam facility, a new ECR ion source and cyclotron control system will be constructed.

Commissioning of the upgraded IGISOL facility and the new vacuum-mode separator MARA will open up new possibilities in studies of neutron-rich as well as proton-drip-line nuclei.

**Special student programs:**
The Laboratory itself is a training site. It has acted as an EU Marie Curie Training site. It regularly runs a Summer School for postgraduate students, and has a program of Summer Student Training aimed at undergraduates.
4 MV VAN DE GRAAFF ACCELERATOR
INSTITUTION: INSTITUT DE PHYSIQUE NUCLEAIRE DE LYON (IPNL)

Lyon (France)

Institut de Physique Nucléaire de Lyon
(in2p3-CNRS/Université Claude Bernard Lyon)

4, rue Enrico Fermi
69622 Villeurbanne- France

Telephone: +33 (0)4 72 44 79 96
Facsimile: +33 (0)4 72 43 13 54
E-mail peaucelle@ipnl.in2p3.fr

French mix Unity of research University of Lyon/ CNRS
(National Centre for Scientific Research)

Construction: HVEC (The Netherlands)
Operation: IPNL (in2p3-CNRS/ University of Lyon) + business service

Heads of the facility:
Mr Guy Chanfray (Director)
Mr Christophe Peaucelle (head of accelerator division)

Scientific Mission and Research Programs:

There are mostly two main researches on the 4 MV accelerator:

On one hand, the 4 MV van de Graaf accelerator is used for research about nuclear waste management: first one, as a particles source for study on effects and damages on matrices after irradiation;

Secondly, different ion-beam-analysis methods (such as RBS, PIXE, ERDA and NRA) are powered in order to follow and determine migration of several isotopes which simulate long life radio element inside nuclear waste matrices.

On the other hand, argon ions are used for application of Time-of-Flight Mass Spectrometry to the analysis of environmental samples such as pesticides adsorbed on soils.

Besides, facility is uses for ionic implantation and practical for undergraduate and graduate students

Finally, our laboratory develops business implantation and analysis services for others labs or firms.

Characterization of the facility:

4 MV Electrostatic accelerator Van de Graaff used for ionic implantations and ion beam analysis:
Nuclear Reaction Analysis, Rutherford Backscattering Spectroscopy, Particles
Induced X-ray Emission, Elastic Recoil Detection Analysis)

3 beams lines dedicated to TOF, RBS+ERDA+PIXE, Ionic Implantations, Extract beam line

Facility Parameters:

<table>
<thead>
<tr>
<th>Accelerated ions:</th>
<th>Protons</th>
<th>Deutons</th>
<th>He$_{3}$</th>
<th>He$_{4}$</th>
<th>N$_{15}$</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable Charges:</td>
<td>1+</td>
<td>1+</td>
<td>1+/2+</td>
<td>1+/2+</td>
<td>1+/2+</td>
<td>1+/2+/3+</td>
</tr>
<tr>
<td>Enable Energies:</td>
<td>3.5 MeV</td>
<td>3.5 MeV</td>
<td>3.5/7 MeV</td>
<td>3.5/7 MeV</td>
<td>3.5/7 MeV</td>
<td>3.5/7/9</td>
</tr>
<tr>
<td>Enable Intensities:</td>
<td>400 nA</td>
<td>400 nA</td>
<td>400/50 nA</td>
<td>400/50 nA</td>
<td>400/50 nA</td>
<td>100/30/10</td>
</tr>
</tbody>
</table>
Technical facilities:

Bending magnet of the 4MV Van de Graaf accelerator

Major experimental instrumentation and its capabilities:
Instrumentation for ion beam analysis: Nuclear Reaction Analysis, Rutherford Backscattering Spectroscopy, Particles Induced X-ray Emission, Elastic Recoil Detection Analysis

Nature of user facility:
Yes

Program Advisory Committee/experiment proposals:
Yes, an internal one

Number of actual, active users of the facility in a given year:
In 2012, there were about 20 active users divided in 2 subjects of research

Percentage of users, and percentage of facility use that come from inside the institution:
95%

Percentage of users and percentage of facility use from national users:
100%

Percentage of users and percentage of facility use from outside the country where your facility is located:
0%

Fraction of the international users outside geographical region:

User Group:
Yes, two formal users group (11 p. and 6 p.)

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
permanent staff: technical staff: 6
permanent user staff: 9
temporary staff: 7

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
0

Number of postdoctoral researchers:
0

Number of graduate students resident at the facility:
6

Special student programs:
Practical for under graduate and graduate students

Future Plans:
Replacement by a new one but not founded
GIP ARRONAX
1 Rue Aronnax
BP 10112
44817 Saint-Herblain cedex

Telephone: +33 228 21 21 21
Facsimile: +33 2 40 94 8130
E-mail: name_at_arronax-nantes.fr

Groupement d’ Intérêt Public (Association of public partners):
CHU de Nantes, CNRS/IN2P3, CLCC Nantes Atlantique, École des Mines de Nantes, Etat, Inserm
Région des Pays de la Loire, Université de Nantes

a) Local authorities, French State, European Union
b) CNRS/IN2P3, Inserm, CLCC Nantes Atlantique, Ecole des Mines de Nantes, Université de
Nantes + customers

Heads of the facility:
Olivier Laboux, President
Jacques Barbet, Director

Scientific Mission and Research Programs:
The high-energy cyclotron Arronax, located in Nantes, is dedicated to nuclear medicine, radiochemistry and education. The main purpose of this equipment is to produce innovative electron-, positron-, and alpha-emitting radionuclides for diagnostic and therapeutic applications developed in research laboratories and hospital-based nuclear medicine departments and to advance knowledge about radiation and matter interactions.
The cyclotron was commissioned in 2010 cumulating with a 24h runs at 750 µA. Since then, regular high and low intensity runs over several days are performed.

Technical facilities:
Characterization of the facility:

High-energy cyclotron with light-ion beams

Facility Parameters:

- Protons: 30-70 MeV, up to 750 µA (only 375 µA per reaction vault, 2 beams in parallel)
- Alpha particles: 68 MeV, up to 35 µA
  1 alpha particle vertical beamline
  Alpha pulsation: pulse width: 45 ns – pulsation: 1 pulse per n * 330 ns (n : integer)
- Deutons : 15-35 MeV, up to 50 µA - HH+: 17.5 MeV protons, 50 µA proton

Major experimental instrumentation and its capabilities:

Faraday cups, collimators are available in beamlines
All instrumentation at end of beamline comes from users

Nature of user facility:

Yes – The users comes from partners and other French and international institutions. Some industrial companies may also use the beam.

Program Advisory Committee/experiment proposals:

Yes, the International Scientific Committee.

Number of actual, active users of the facility in a given year:

5

Percentage of users, and percentage of facility use that come from inside the institution:

Not known today

Percentage of users and percentage of facility use from national users:

Not known today

Percentage of users and percentage of facility use from outside the country where the facility is located:

Not known today

Fraction of international users outside of geographical region:

Not known today

User Group:

Not known today

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

Permanent staff: 9

Number of theoretical staff employed at the facility: permanent, postdoctoral, students:

30

Number of postdoctoral researchers:

0*
Number of graduate students resident at the facility: 3*

Number of non-resident graduate students with thesis work primarily done at the facility: 4*

Involvement of undergraduate students in research (approximate average number at a given time): 10*

Special student programs: In preparation

Future Plans:
EUROPEAN SYNCHROTRON RADIATION FACILITY
ESRF GRAAL – GRENOBLE ANNEAU ACCÉLERATEUR LASER

Grenoble (France)

6, rue Jules Horowitz BP220 38043
Grenoble CEDEX9, France
Telephone: +33 (0) 4 76 88 20 00
Facsimile: +33 (0) 4 76 88 20 20
web address: http://www.lnf.infn.it/nuclear

ESRF: W.G. Stirling
INFN: R. Petronzio

Société Civile under French law

For Graal: Government funds via the Italian agency for nuclear physics INFN – Istituto Nazionale di Fisica Nucleare

Heads of the facility:
Prof. Roberto Petronzio
Prof. Carlo Schaerf

Scientific Mission and Research Programs:
The scientific goal of the Graal Beam Facility is the study of the barion spectrum through the measurement of polarisation degrees of freedom in photonucleon reactions with monochromatic and polarised (circular or linear polarisation) γ rays in the second and third resonance region. Current research include meson photoproduction on the proton and on the neutron, strangness photoproduction, Compton scattering.

Graal has terminated its data data taking activity at the end of 2008.

Technical facilities:
Brief characterization of the facility:
Compton back-scattered polarised photon beam

Table of facility parameters:

<table>
<thead>
<tr>
<th>Laser line (nm)</th>
<th>$\gamma$ energy (MeV)</th>
<th>Intensity ($s^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>514 (green)</td>
<td>550-1100</td>
<td>$5 \times 10^6$</td>
</tr>
<tr>
<td>351 (UV)</td>
<td>950-1500</td>
<td>$2 \times 10^6$</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:
Lagrange a $4\pi$ detector for charged and neutral particles with excellent energy resolution to 1-1000 MeV photons (BGO calorimeter with 480 elements), high neutron detection efficiency (20-50%), no magnetic field.

Nature of user facility:
The facility is advertised as user facility only informally and is available for scientific users through collaborative programs at the discretion of the Graal collaboration.

Program Advisory Committee/experiment proposals:
The beam time is allocated through an internal committee.

Number of actual, active users of the facility in a given year (average over the last few years, or just the last year if the facility is new, for example; please indicate how the number is derived):
35

Percentage of users, and percentage of facility use that come from inside the institution:
INFIN 60%
ESRF 0%

Percentage of users and percentage of facility use from national users:
50% from Italy.

Percentage of users and percentage of facility use from outside the country where your facility is located:
80% from outside France (estimate)

Fraction of international users outside of geographical region:
0%

User Group:
No

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
0

Number of theoretical staff employed at the facility: permanent, postdoctoral, students:
No direct theoretical staff is directly involved in running the experiment.

Number of postdoctoral researchers:
Presently 25

Number of graduate students resident at the facility:
Presently none.

Number of non-resident graduate students with thesis work primarily done at the facility:
2

Involvement of undergraduate students in research (approximate average number at a given time):
2

Special student programs:
No

Future Plans:
The facility has terminated its activity effective the end of 2008.
FACILITY AIFIRA (APPLICATIONS INTERDISCIPLINAIRES DES FAISCEAUX D'IONS EN REGION AQUITAINE) AT THE LABORATORY CENBG

Centre d’Etudes Nucléaires Bordeaux Gradignan (CENBG) 
Chemin du Solarium 
Le Haut Vigneau, BP 120, 33175 GRADIGNAN, FRANCE

Telephone: +33 5 57 12 08 00 
Facsimile: +33 5 57 12 08 02 
E-mail: moretto@cenbg.in2p3.fr 

The laboratory is a mixed unit of research (UMR) CNRS/IN2P3, CNRS/INC, 
University of Bordeaux

Region Aquitaine, the ministry of Research and Education, the French National Research Council (CNRS) and the University Bordeaux 1 for the construction CNRS and University of Bordeaux for the operation

Heads of the facility:

Pr. Philippe Moretto, scientific coordinator of the facility, head of the laboratory 
e-mail: moretto@cenbg.in2p3.fr
Dr Stéphanie Sorieul, access manager 
e-mail: sorieul@cenbg.in2p3.fr

Scientific Mission and Research Programs:

Activities of the laboratory extend from nuclear to astroparticle physics, and beyond to applications of subatomic physics to different multidisciplinary fields. The main research topics are: Exotic nuclei far from the valley of beta stability, and rare decays modes - Neutrino physics (type and mass) and double beta decay - High energy gamma ray astronomy - Laser induced nuclear excitations - Theoretical study of nuclear and hadronic matter - Environment and Radiation Biology - The AIFIRA facility has been commissioned beginning 2006: the addressed topics cover different fields of research including life sciences, environment, archaeology, solid state physics, microelectronics, neutron physics, waste transmutation, nuclear fuel cycles and industrial applications.

Technical facilities:
Characterization of the facility:

Accelerator: Single stage, 3.5 MV electrostatic accelerator (Online 3.5 MV Singletron, HVEE, The Netherlands) providing light ions beams

Facility Parameters:

Ion energy range from 0.3-3.5 MeV, energy stability better than $2.10^{-5}$
- protons $^1$H$^+$, max current 80 µA,
- deuterons $^2$H$^+$, max current 50 µA,
- helium $^4$He$^+$, max current 50 µA,

Lateral resolution ranging from a few mm down to 200 nm (nanometer) on focused beamlines

Mono energetic neutron beams from 0.1 to 7 MeV, flux $\sim 10^6$ neutrons / cm$^2$.sec

Major experimental instrumentation and its capabilities:

Five beam lines each dedicated to a special application:
- a line with mm size beam for material characterization and quantitative chemical analysis
- an external beam line for material characterization
- a focused microbeam line for the irradiation of single biological cells in single event mode
- a nanobeam with nm size beam for two- and three-dimensional imaging in tomography
- a line for the production of intense mono-energetic neutron beams produced via nuclear reactions of protons on $^7$Li targets or deuterons on $^2$H.

Nature of user facility:

The facility is a user facility driven by the CENBG under the responsibility of CNRS and the University of Bordeaux 1.

Program Advisory Committee/experiment proposals:

The facility has a programme advisory committee with a panel including 5 external members. There are two users panel meetings per year. About 20 different research teams share 3500 hands-on beam hours every year.

Percentage of users, and percentage of facility use that come from inside the institution:

60 % of the beamtime is used by groups or departments of the local institution (including 20% for industrial activities)

Percentage of users and percentage of facility use from national users:

Within the 40% available beamtime, about 30 % are given to national users. This number depends on the involvement of the facility in European programmes (see hereafter).

Percentage of users and percentage of facility use from outside the country where your facility is located:

The facility is involved (2009-2013) in SPIRIT and ERINDA, two transnational access programmes of the EC - FP7 : on the period, 10% of the beamtime has been devoted to European users.

Fraction of international users outside of geographical region:

The facility is open to users from any regions but up to date, no users from outside Europe.

User Group:

There is no formal user’s group.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) permanent staff : 5 full-time equivalent (scientific + technical staff).

b) temporary staff : 2 post-docs researchers (2011-2013)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

0

Number of postdoctoral researchers:

2 post-docs researchers in the lab (CENBG)

1 post-doc from other institutions.

Number of graduate students resident at the facility:

No resident students

Number of non-resident graduate students with thesis work primarily done at the facility:

7 graduate students in groups sharing the AIFIRA beamtime.

Special student programs:

Student labs for university students in physics from Bachelor degree (3rd year) and Master degrees.


**Future Plans:**

New techniques have been just commissioned or are being commissioned: a new irradiation end-station on the microbeam line for radiation biology (2013). It makes it possible to investigate online mechanisms of molecular dynamics in living individual cells targeted by individual ions in time lapse mode. Laser confocal microscopy is being installed on the beamline for photobleaching of fluorescence markers application (2014).
GRAND ACCELERATEUR NATIONAL D’IONS LOURDS (GANIL)

Caen (France)

Boulevard Henri Becquerel
– BP 55027 –
14076 Caen cedex 5
Telephone: 33 (0)2 31 45 46 47
Facsimile: 33(0)2 31 45 46 65
E-mail: gales@ganil.fr

Groupement d’Intérêt Economique (Economic Interest Group) - GIE

CEA-DSM (Commissariat à l’Energie Atomique/Direction des Sciences de la Matière)
CNRS-IN2P3 (Centre National de la Recherche Scientifique – Institut National de Physique Nucléaire et de Physique des Particules)
Région Basse-Normandie
Union Européenne

Head of the facility:

Director: Sydney GALES
Deputy Director & SPIRAL2 Project Leader: Marcel JACQUEMET
Scientific Deputy Director: Philippe CHOMAZ
SPIRAL2 Scientific Coordinator: Marek LEWITOWICZ

Scientific Mission and Research Programs:

GANIL is a large-scale European facility providing beams of heavy ion from Carbon to Uranium with energies ranging from very slow (few hundred meters per second) to high energies up to 95 MeV per nucleon. The scientific program is developing along 2 lines: (i) the study of the atomic nucleus, its structure and reactions and its mechanical, chemical and thermal properties (ii) the use of the various beams to investigate matter at larger scale from atoms to DNA. GANIL is producing beams of exotic nuclei using the fragmentation method in LISE Spectrometer and the ISOL technique with the SPIRAL facility.). Exotic nuclei are a key point in our understanding of nuclear structure and isospin dependence of the nuclear interaction and matter. They are also important in astrophysics. GANIL is now building a second generation exotic beam facility SPIRAL2.

Technical facilities:

Cf annexe 1
Characterization of facility:
2 separated sector cyclotrons and 3 compact cyclotrons

Technical facilities:
Acceleration of light and heavy ion beams (Carbon to Uranium) from few MeV/nucleon to 95 MeV/nucleon. Exotic beams can be produced by Isotope Separation On Line method with the SPIRAL facility (up to 25 MeV/nucleon) or In-Flight Separation techniques.

Equipment of the experimental areas
- a fragment separator (LISE)
- a large acceptance spectrometer (VAMOS)
- a high resolution spectrometer (SPEG)

These 3 spectrometers can be coupled to different devices available on site: a large solid angle, high efficiency gamma detector (EXOGAM), several modular set-ups for light charged particles (MUST2,TIARA), the Neutron Wall array, Indra 4π multidetector for charged particles.....

Three beam lines are available for atomic, condensed matter physics, radiochemistry and radiobiology, at very low energy (below 1MeV/nucleon), at medium energy (~10MeV/nucleon) and at full energy, allowing a broad range of experiments.

GANIL in the future with SPIRAL2

Nature of user facility
GANIL has been considered as a user facility (since 95) by the European Commission through the Integrated Infrastructure Initiative Contract “EURONS”

Program Advisory Committee/experiment proposals:
2 PACs one for Nuclear Physics (7 foreign,5 national) and one for interdisciplinary research (atomic, condense matter, biology) Industrial applications do no go through the PAC’s. Both PAC’s are run twice a year.

Number of actual, active users of the facility in a given year (average over the last few years; for example; please indicate how the number is derived)

The three-year average for the period 2006-2008 inclusive is 630 users. This doesn’t include numerous collaborators who do not participate in the on-site running of experiments. (active users is
interpreted as physicists coming on site to run experiments)

**Percentage of users, and percentage of the facility users that come from inside the institution:**

2006-2008 period: 10% of users come from inside GANIL

**Percentage of users and percentage of facility use from national users:**

For the period 2006-2008, national users represent 55% of the users for the nuclear physics

**Percentage of users and percentage of facility use from outside where your facility is located:**

Period 2006-2008: 45%

**Fraction of the international users outside geographical region:**

11% (outside EU)

**Users group:**

GANIL Users Board, composed of 10 members, elected by the community of users, with 4 years mandate.

**Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):**

Permanent staff: 250
Temporary Staff: 50

**Number of theoretical staff employed at the facility: permanent; postdoctoral; students:**

4, permanent; 1 post-doc, 3 PhD students

**Number of postdoctoral researchers:**

Currently 14; varies between 6 and 20

**Number of graduate students resident at the facility:**

Currently 15

**Number of non-resident graduate students with thesis work primarily done at the facility:**

About 20 per year non-resident graduate students

**Involvement of undergraduate students in research (approximate average number at a given time):**

About 40 per year (estimate for Ganil only)

**Special student programs:**

A summer school for high school, undergraduate and graduate students
Trainings for undergraduate, high school students
Thesis presentation day for undergraduate
Open doors for high school students

**Future Plans:**

The major development at GANIL in the next 5 years is the construction of the new radioactive beam facility SPIRAL2 which is on the road map toward EURISOL. At the same time the associated instrumentation is under development with for example a new spectrometer for the search for super-heavies or a new low energy cave for the study of radioactive elements.
Implanteur 400 KV Institution: Institut de Physique Nucléaire de Lyon (IPNL)

Lyon - France

Institut de Physique Nucléaire de Lyon
(in2p3-CNRS/Université Claude Bernard Lyon)

4, rue Enrico Fermi
69622 Villeurbanne- France
Telephone: +33 (0)4 72 44 79 96
Facsimile: +33 (0)4 72 43 13 54
E-mail peaucelle@ipnl.in2p3.fr

French mix Unity of research University of Lyon/ CNRS
(National Centre for Scientific Research)

Construction: PACE program + IPNL (in2p3-CNRS/ University of Lyon)
Operation: IPNL (in2p3-CNRS/ University of Lyon) + business service

Heads of the facility:
Mr Guy Chanfray (Director)
Mr Christophe Peaucelle (head of accelerator division)

Scientific Mission and Research Programs:
This accelerator is exclusively used for ionic implantation. Nuclear waste management is the main research program: indeed, this field of research needs to simulate several radio elements by mean of implanted ions in nuclear waste matrices.

Besides, our laboratory develops business implantation service for other labs or firms

Technical facilities:

400 kV Implanteur
Characterization of the facility:
Ion implanter (energy from 60 keV to 800 keV)

Facility Parameters:
Produced ions: He, N, C, Cs, Mg, Al, Cl, Ar, Fe, Pb, Ag, Au, Ti, Cr, Kr, I, Xe, Eu, Er, Ne, Li, O, Ni, Se, Zr, Lu, Nd…
Max. high voltage: 400 kV
Max source intensity: 4 mA
Max selected ion intensity: several hundred of µA
Max implanted area: 80 cm²

Major experimental instrumentation and its capabilities:
Nature of user facility:
No
Program Advisory Committee/experiment proposals:
No
Number of actual, active users of the facility in a given year:
Over 100 uses per a year
Percentage of users, and percentage of facility use that come from inside the institution:
80 % from inside the institution
Percentage of users and percentage of facility use from national users:
99 % from national users
Percentage of users and percentage of facility use from outside the country where your facility is located:
1 %

Fraction of international users outside of geographical region:
0 %

User Group:
No
Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
Technical staff: 2
Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
0
Number of postdoctoral researchers:
0
Number of graduate students resident at the facility:
0
Number of non-resident graduate students with thesis work primarily done at the facility:
0
Involvement of undergraduate students in research (approximate average number per year):
0
Special student programs:
0
Future Plans:
INSTITUT LAUE-LANGEVIN

Grenoble ILL (France)

6 rue Jules Horowitz
BP 156
Grenoble Cedex 9
F-38042
Facsimile: +33 4 76 48 39 06
WWW: http://www.ill.fr/

Dr. Richard Wagner, Director
Telephone: +33 4 76 20 71 74
E-mail: carlile@ill.fr

Contact Person for Foreign Users
G. Cicognani
Telephone: +33 4 76 20 70 82
Facsimile: +33 4 76 48 39 06
E-mail: sco@ill.fr

Facility:
High-Flux 58.4 MW Reactor: The most powerful source of neutrons in the world for research, operating some 40 instruments. Maximum unperturbed thermal neutron flux in reactor: $1.0 \times 10^{15}$ n/cm²/s. Maximum perturbed thermal-neutron flux at beam tubes: $0.8 \times 10^{15}$ n/cm²/s.

Hot source at 2400 K. Vertical and horizontal cold sources at 25 K.

Procedure to Apply for Beamtime:
Proposals for experiments at the ILL are submitted from the “visitor’s club” on the ILL’s website (www.ill.fr). Two proposal rounds per year, on 15 February and 15 September.

Programme Advisory Committee (current membership):
9 different PAC subcommittees each specialised in a particular scientific field (one subcommittee for nuclear and fundamental physics). Each PAC has 8 to 10 external members.

Main Instrumentation for Nuclear Physics Experiments:
Four main instruments: Lohengrin (PN1), GAMS (PN3), PF1 and PF2. The Lohengrin online mass spectrometer for unslowed fission products, which produces and separates neutron-rich nuclei far from stability. The focal point of the spectrometer can be equipped with, ionisation chambers for particle identification, an efficient array of “Clover” detectors for γ-ray spectroscopy, BaF₂ detectors for fast-timing measurements and Si(Li) detectors for conversion-electron spectroscopy. These detectors are used mostly for the studying decays from microsecond isomers. A tape transport is also available for beta-decay studies. Studies of the fission process and applied physics experiments related to reactor applications can also be performed with this instrument. The GAMS 4 and 5 ultra-high resolution crystal gamma-ray spectrometers have eV resolution and can be used for ultra-high resolution gamma-ray spectroscopy, measurements of nuclear lifetimes on the femtosecond scale, the
determination of fundamental constants and the low-energy slowing down processes of ions in matter. The PF1 cold-neutron beam, with a thermal-equivalent flux of $1.4 \times 10^{10}$ n/cm$^2$/s delivers the most intense cold polarised neutron beam in the world. It can be used for experiments such as the study of asymmetries in neutron decay, nuclear structure (through fission or neutron-capture reactions) and studies of the fission mechanism.

PF2 ultra-cold neutron facility provides beams of ultra-cold neutrons. Examples of experiments include studies of the electric dipole moment of the neutron and measurements of the neutron lifetime.

**Main Fields of Nuclear Research:**
Nuclear structure of neutron-rich nuclei far from stability. Nuclear structure from neutron-capture reactions.

**Main Fields of Other Research:**
Research at the ILL covers nearly all areas of physics, chemistry, biology, materials science and engineering.

**Accommodation:**
Joint guest house (with the ESRF) with 114 single rooms and 20 twin rooms located at the laboratory.

**Transportation:**
Train station Grenoble (2 km from the laboratory). Grenoble, Lyon and Geneva airports all within easy reach by road (all have regular coach services).
The Tandem/ALTO facility, it is under the responsibility of the Institute. It therefore has the same status.

Heads of the facility:

Pr Dominique GUILLEMAUD-MUELLER
Dr Fadi IBRAHIM, Head of the Tandem and ALTO facilities (scientific matters);
Dr Saïd ESSABAA, Head of the Tandem and ALTO facilities (technical matters).

Scientific Mission and Research Programs:

The physics fields are:
fundamental nuclear physics,
nuclear structure, exotic nuclei;
nuclear astrophysics;
solid physics;
atomic physics.

Characterization of the facility:

The Tandem is an electrostatic machine (maximum voltage 15 MV). It can speed up an important range of ions, from the protons to the mass aggregates, ALTO is a 50 MeV pulsed electron linac, dedicated to the production of neutron rich radioactive beams with a production up to 4.10" fissions per second, on line with a mass separator.
Table of facility parameters:
Tandem:

<table>
<thead>
<tr>
<th>Injected ion species</th>
<th>Injected intensity (µA)</th>
<th>Energy (MeV)</th>
<th>Intensity analysed (pps x 10^10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 H</td>
<td>2.5</td>
<td>25</td>
<td>600</td>
</tr>
<tr>
<td>2 H</td>
<td>1.6</td>
<td>29</td>
<td>113</td>
</tr>
<tr>
<td>4 He</td>
<td>1.9</td>
<td>36</td>
<td>900</td>
</tr>
<tr>
<td>6 Li</td>
<td>0.07</td>
<td>50</td>
<td>1.8</td>
</tr>
<tr>
<td>7 Li</td>
<td>0.09</td>
<td>56</td>
<td>13</td>
</tr>
<tr>
<td>9 Be</td>
<td>0.0025</td>
<td>62</td>
<td>0.56</td>
</tr>
<tr>
<td>11 B</td>
<td>0.0042</td>
<td>77</td>
<td>4.3</td>
</tr>
<tr>
<td>12 C</td>
<td>0.92</td>
<td>69</td>
<td>94</td>
</tr>
<tr>
<td>13 C</td>
<td>1.8</td>
<td>70</td>
<td>2.6</td>
</tr>
<tr>
<td>14 C</td>
<td>0.11</td>
<td>72</td>
<td>15</td>
</tr>
<tr>
<td>16 O</td>
<td>4</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>19 F</td>
<td>0.2</td>
<td>104</td>
<td>3.3</td>
</tr>
<tr>
<td>24 Mg</td>
<td>0.06</td>
<td>130</td>
<td>6</td>
</tr>
<tr>
<td>27 Al</td>
<td>0.18</td>
<td>120</td>
<td>8</td>
</tr>
<tr>
<td>28 Si</td>
<td>0.14</td>
<td>150</td>
<td>0.063</td>
</tr>
<tr>
<td>31 P</td>
<td>0.07</td>
<td>155</td>
<td>0.95</td>
</tr>
<tr>
<td>32 S</td>
<td>0.75</td>
<td>154</td>
<td>29</td>
</tr>
<tr>
<td>34 S</td>
<td>0.09</td>
<td>130</td>
<td>5.6</td>
</tr>
<tr>
<td>35 Cl</td>
<td>0.2</td>
<td>154</td>
<td>10</td>
</tr>
<tr>
<td>40 Ga</td>
<td>0.12</td>
<td>168</td>
<td>37</td>
</tr>
<tr>
<td>48 Ti</td>
<td>0.014</td>
<td>210</td>
<td>1.2</td>
</tr>
<tr>
<td>56 Fe</td>
<td>0.0025</td>
<td>99</td>
<td>0.032</td>
</tr>
<tr>
<td>58 Ni</td>
<td>0.18</td>
<td>182</td>
<td>6.8</td>
</tr>
<tr>
<td>81 Br</td>
<td>1.5</td>
<td>217</td>
<td>2.2</td>
</tr>
<tr>
<td>127 I</td>
<td>0.5</td>
<td>297</td>
<td>0.5</td>
</tr>
<tr>
<td>197 Au</td>
<td>0.2</td>
<td>172</td>
<td>0.045</td>
</tr>
</tbody>
</table>

ALTO: neutron rich radioactive beams with production up to 4.10^{11} fissions/sec.

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:
- Split pole spectrometer
- Parnme separator
- Bacchus spectrometer
- Orsay Segmented Clover Array (OSCAR)

Nature of user facility:
YES

Program Advisory Committee/experiment proposals:
YES

The ALTO Programme Advisory Committee adjudicates experiment proposals twice a year.

Number of active users and their origin:
Just with the Tandem facility: 130 active users of the facility. This number will increase with ALTO (end of 2005).

Percentage of users, and percentage of facility use that come from inside the institution:
22 %

Percentage of users and percentage of facility use from national users:
42 %

Percentage of users and percentage of facility use from outside the country where your facility is located:
34 %

Fraction of the international users outside of geographical region:
2 %

User Group:
Not for the moment, in progress.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
a) 28, b) 10

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
20 permanent theoretical staff, 2 post-doc theoretical staff, 6 students at IPN.

Number of postdoctoral researchers:
10 at IPN

Number of graduate students resident at the facility:
42 at IPN

Number of non-resident graduate students with thesis work primarily done at the facility:
5

Involvement of undergraduate students in research (approximate average number at a given time):
10

Special student programs:
Master experiments: once a year, schools visits (under graduates).

Future Plans:
Construction of 4 low energy lines, in addition with the one already existing. Laser Ion source, high resolution spectrometer,
DARMSTADT S-DALINAC (GERMANY)

Institut für Kernphysik
Technische Universität Darmstadt
Schlossgartenstrasse 9
D-64289 Darmstadt

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Telephone: +49 61 51 16 74 41
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E-mail: Pietralla@ikp.tu-darmstadt.de

Professor Dr. Dr. h.c. Norbert Pietralla
Dr. Florian Hug

Scientific Mission and Research Programs:
Main Fields of Nuclear Research:
- Photon and electron scattering for the study of elementary nuclear excitations with low multipolarity.
- Electric and magnetic giant resonances.
- Precision measurements on few-body systems and effective nuclear few-body forces.
- Nuclear astrophysics.
- Electromagnetic analogues of electroweak nuclear reaction matrix elements

Technical facilities:
Layout: S-DALINAC + Exp. Facilities
Fig caption
1. Nuclear Resonance Fluorescence (gamma,gamma’) – experiments.
2. Energy-recovery mode (in prep.)
3. High-energy radiation physics
4. High-resolution (30 keV) tagged photons up to 30 MeV
5. (e,e’x) – experiments & 180° spectrometer
6. (e,e’) – experiments
7. Optics experiments
Characterization of the facility:
Superconducting recirculating electron beam accelerator.

Table of facility parameters:
beam: electrons
energy: 2-130 MeV
current: 50 µA (10 MeV), 20 µA (130 MeV)
energy resolution of beam on target: < 4 x 10^-4

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:
Main Instrumentation for Nuclear Physics Experiments:
Nuclear resonance fluorescence facility with three 100% efficient Germanium detectors and AGATA-type Compton-tracking polarimeter
Large solid angle magnetic spectrometer of the QCLAM type for single arm (e,e’) and coincidence experiments of the form (e,e’x) with x = n,p,g …
Solid state and neutron counter arrays
Energy-loss (e,e’)-spectrometer at high resolution
Facility for inelastic electron scattering under 180º

Nature of user facility:
no; mainly inside users,
outside users are welcome if in-house group serves as host. Contact director for facility access.

Program Advisory Committee/experiment proposals:
no

Number of active users and their origin:
Masters + doctoral students + scientific staff: 30+25+16 = 71

Percentage of users, and percentage of facility use that comes from inside the institution:
mainly inside users (~90%)

Percentage of users and percentage of facility use from national users:
≤ 5%

Percentage of users and percentage of facility use from outside the country where your facility is located:
≤ 5%

Fraction of international users outside of geographical region:
2% 2% 50%

User Group:
no

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
9; 7; 25

Number of postdoctoral researchers:
9

Number of graduate students resident at the facility:
55

Number of non-resident graduate students with thesis work primarily done at the facility:
-

Involvement of undergraduate students in research:
20

Special student programs:
Accelerator school, Graduate school HGS-HIRe

Future Plans:
Future Developments (under construction):
- Third recirculation arch
- Energy-recovery mode
- 20-unit LaBr-ball
- Semiconductor charged-particle counter ball
- Helium targets
- Further increase of beam-energy resolution
DEUTSCHES ELEKTRONEN-SYNCHROTRON, DESY

Hamburg and Zeuthen

DESY in Hamburg
Notkestraße 85
22607 Hamburg, Germany
Telephone: +49 40/8998-0
Facsimile: +49 40/8994-3282
E-mail: desyinfo@desy.de

DESY in Zeuthen
Platanenallee 6
15738 Zeuthen, Germany
Telephone: +49 33762/77-0
Facsimile: +49 33762/77-413
E-mail: desyinfo.zeuthen@desy.de

DESY is organized as a foundation under civic law. It is member of the Helmholtz Association of German research centres.

DESY is publicly financed by the federal ministry BMBF (Bundesministerium für Bildung und Forschung) and by federal states Freie und Hansestadt Hamburg (DESY in Hamburg) and Brandenburg (DESY in Zeuthen).

The research centre is headed by a board of six directors.

Heads of the facility:

Prof. Dr. R.-D. Heuer - Director in charge of High Energy Physics and Astroparticle Physics
C. Scherf - Director in charge of Administration
Prof. Dr. J. R. Schneider - Director in charge of Research with Photons
Dr. D. Trines - Director in charge of Accelerator Physics
Prof. Dr. A. Wagner - Chairman of the DESY Directorate
Dr. U. Gensch - Representative of the DESY Directorate in Zeuthen

Scientific Mission and Research Programs:

DESY conducts basic research in the natural sciences with special emphasis upon
- the development, construction and operation of accelerator facilities
- particle physics (investigation of the fundamental properties of matter and forces)
- research with photons (investigations in all fields of natural sciences using a special light generated at accelerators).

About 3000 scientists from 34 countries visit DESY every year for research at the DESY facilities.
Technical facilities:

Presently DESY has three main facilities providing beams for experimental physics:

**HERA** is a storage ring to scatter 27.7 GeV electrons / positrons off 920 GeV protons. These collisions are detected by the experiments H1 and ZEUS. The lepton beam is employed for the fixed target experiment HERMES.

HERA consists of several pre-accelerators. For general use an electron test beam up to 7 GeV is provided by one of them, the pre-accelerator DESY, in parallel.

The storage ring DORIS is a dedicated synchrotron radiation source with wiggler/undulator insertion devices and several dipole beamlines.

The VUV-FEL is a superconducting linear accelerator with free-electron laser which generates radiation according to the SASE principle. Beside that DESY is developing and operating a photo injector test stand at Zeuthen (PITZ) used also for
studies in relation with the VUV-FEL and the XFEL (see below).

HERA operation will come to an end by mid of 2007. DESY will then convert the storage ring PETRA (presently used as a pre-accelerator) into a new high-brilliance synchrotron radiation source PETRA III.

In cooperation with international partners, the European XFEL facility will be realized in Hamburg. It will provide extremely intensive, ultrashort X-ray flashes with laser light properties.

**Table of facility parameters:**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Beam Species</th>
<th>Max Energy (GeV)</th>
<th>Circumference or Length (m)</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERA</td>
<td>e- or e+ and p</td>
<td>30 and 920</td>
<td>6336</td>
<td>e-/+p-scattering</td>
</tr>
<tr>
<td>DESY</td>
<td>e-</td>
<td>7</td>
<td>293</td>
<td>Pre-accelerator, Test Beam, Synchrotron radiation</td>
</tr>
<tr>
<td>DORIS</td>
<td>e+</td>
<td>4.45</td>
<td>289</td>
<td>Synchrotron radiation</td>
</tr>
<tr>
<td>VUV-FEL</td>
<td>e-</td>
<td>0.380</td>
<td>260</td>
<td>Synchrotron radiation</td>
</tr>
<tr>
<td>PITZ</td>
<td>e-</td>
<td>0.015</td>
<td>~5</td>
<td>Test Beam, Synchrotron radiation</td>
</tr>
<tr>
<td>PETRA*</td>
<td>e-</td>
<td>12</td>
<td>2304</td>
<td>Synchrotron radiation</td>
</tr>
<tr>
<td>XFEL*</td>
<td>e-</td>
<td>17.5</td>
<td>~3000</td>
<td>Synchrotron radiation</td>
</tr>
</tbody>
</table>

* Planned for the near future.

**Brief and compact table with the facility’s major experimental instrumentation and its capabilities:**

HERA has two collider experiments, H1 and ZEUS, which are complex 4π detectors with weight of several hundred tons consisting of tracking devices and calorimeter components. The goal is to study e-/+p-scattering in order to investigate the structure of the proton and properties of fundamental forces, in particular strong and electroweak forces. HERMES is a fixed target experiment using the HERA electron beam to examine the intrinsic angular momentum – or spin – of protons and neutrons.

The synchrotron radiation at DESY is used in many different ways in fundamental and applied research in the fields of physics, biology, chemistry and crystallography, in materials and geological sciences as well as in medical applications. The wide spectrum of electromagnetic radiation ranges from the visible to the hard X-ray regime and covers an energy domain from about 1 eV to 300 keV. The experimental instrumentation is mainly based on small or wide angle scattering experiments using general purpose detectors.

**Nature of user facility:**

DESY is a user facility visited by about 3000 scientists from 34 countries every year.

**Program Advisory Committee/experiment proposals:**

The research programmes at DESY are reviewed by a Scientific Council, a Physics Research Committee (PRC), a Machine Advisory Committee (MAC) and a Photon Science Committee (PSC), each consisting of external members. Beside this DESY is reviewed every five years within the Helmholtz Association.

**Number of active users and their origin:**

On average DESY facilities are used by 3000 user per year; about half of them from abroad. *(Although it is difficult to precisely determine, we estimate that of these users approximately 10% are in the field of nuclear physics.)*

**Percentage of users, and percentage of facility use that come from within the institution:**

In 2004 the composition of users was as following: About 5% came from inside DESY. 53% of all users came from outside Germany (23% of them were working in High Energy Physics with an average length of stay of five months per year, 30% of them in the field of synchrotron radiation with an average length of stay of one month per year).

**Percentage of users and percentage of facility use from national users:**

42% of facility use from national users plus 5% DESY staff.

**Percentage of users and percentage of facility use from outside the country where your facility is located:**

53% of all users came from outside Germany.

**Fraction of international users outside of geographical region:**

DESY is associated scientifically with institutes from Europe (25 countries), Asia (5), North America (2) and South America (2).
User Group:

Formal user groups exist for all major instruments in high energy physics and also start to be established in the research field of synchrotron radiation.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):

In 2004 the total number of employees was 1695. 1114 of them were permanent staff. The temporary staff consists of 581 people, 163 of them were graduate students and postdoctoral researchers.

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

In 2004 together 14 permanent and 36 postdoctoral and students worked at DESY in theoretical physics.

Number of postdoctoral researchers:

92 postdoctoral researchers were employed by DESY in 2004.

Number of graduate students resident at the facility (> 80 % of their time):

More than 100 graduate students were resident at DESY in 2004.

Number of non-resident graduate students with thesis work primarily done at the facility:

More than 100 non-resident graduate students worked on a thesis primarily related to DESY research in 2004.

Involvement of undergraduate students in research (approximate average number at a given time):

45 undergraduate students have been involved in research at DESY in 2004.

Special student programs:

A yearly summer student programme attracts approximately 100 students from all over the world (typically selected from about 250 applicants) to DESY for 8 weeks during the summer season. The programme consists of lectures on Particle Physics, accelerators and research with synchrotron radiation. The main attraction of the school, however, is the opportunity to work in one of the research groups at DESY. Independent of the summer student programme DESY is hosting several DAAD students from abroad, like for example from Mexico. Every year, the Association of the Friends and Sponsors of DESY awards a prize to the best PhD thesis produced at one of the DESY experiments.

Future plans:

The success of DESY lies in its synergy between development, construction and operation of accelerators, elementary particle physics (from high energy physics, nuclear physics to Astroparticle Physics) and research with synchrotron radiation. Innovative accelerators, like DORIS, PETRA, HERA and the VUV-FEL have been successfully built and operated for researchers in both these fields. These unique scientific tools have resulted in a wealth of important results in many areas of scientific endeavour. They also attract a large national and international user community to the DESY campus and engender a creative and exciting scientific culture. DESY’s aim is to maintain and further develop this interdisciplinary culture. In support of the construction of the PETRA III storage ring and the European X-ray Laser Project XFEL, the accelerator department of DESY will largely concentrate its activities on the development and construction of accelerator based light sources. As a further consequence DESY decided to build up a strong in-house research activity for preparation of the scientific programme at the XFEL as well as the related instrumentation. DESY participates in the preparatory work of the International Linear Collider (ILC) which will be based on superconducting TESLA technology developed by DESY and its partners in the frame work of the TESLA Collaboration. Besides this a strong theory group at DESY is an important asset. DESY is also providing competitive computing resources for the user groups on campus and for the community (e. g. HERA, LHC, Grid) and for the German Lattice Community.
ELSA, UNIVERSITY OF BONN (GERMANY)

Physikalisches Institut
der Universität Bonn
Nußallee 12
D-53115 Bonn

WWW: http://pi.physik.uni-bonn.de/

Prof. Dr. F. Klein, Director
Telephone: +49 228 73 2340
Facsimile: +49 228 73 3518
E-mail: klein@physik.uni-bonn.de

Contact Person for Foreign Users
Director

Facility:
Storage and stretcher ring ELSA with two pulsed linear accelerators and booster synchrotron producing polarised (1 nA) and unpolarised (up to 10 nA) electron beams from 0.5 to 3.5 GeV with high duty factor. Linearly and circularly polarised photons for hadron physics experiments. Storage of electrons (up to 200 mA) for various applications.

Procedure to Apply for Beamtime:
Contact the director.

Programme Advisory Committee (current membership):
3 national, 6 international members

Main Instrumentation for Nuclear Physics Experiments:
ELSA accelerator with polarised electron source,
Photon taggers with goniometers,
Polarised solid state proton and neutron targets,
Two experimental areas with large solid angle photon spectrometers ,
i.e. Crystal Barrel and BGO-OD ball (Bismuth-Germanate ball with forward magnetic dipole field)

Main Fields of Nuclear Research:
Electron- and photon-induced reactions,
Photoproduction of Mesons,
Baryon Spectroscopy,
In-Medium Properties of Hadrons.

Main Fields of Other Research:
R&D in Accelerator Physics
HEP Detector tests and calibration with single high energy electrons or photons

Accommodation:
Hotels in Bonn, guest rooms.

Transportation:
Public transport.
Forschungszentrum (Research Centre) Jülich (FZJ)  
Institut für Kernphysik/Institute for Nuclear Physics (IKP)  
North Rhine Westphalia, Germany  

Wilhelm-Johnen-Str  
52425 Jülich  
Germany  

Helmholtz Center (HGF e.V.)  
GmbH (Ltd)  
Federal Republic of Germany (90%)  
State of North Rhine Westphalia (10%)  

Prof. Dr. Achim Bachem  
Telephone: +49 02461 61-0  
Facsimile: +49 2461 61-8100  
E-mail: f.goldenbaum@fz-juelich.de  

Head of facility (IKP):  
Prof. Dr. James Ritman (IKP 1)  
Prof. Dr. Hans Ströher (IKP 2)  
Prof. Dr. Ulf-G. Meißner (Theory)  
Prof. Dr. Rudolf Maier (Accelerator)  

Scientific Mission and Research Programs:  

Forschungszentrum Jülich (FZJ) is a multi-disciplinary research center within the framework of the Helmholtz Association. The Institut für Kernphysik (IKP) operates and further develops the Cooler Synchrotron COSY, and makes its beams available to a national and international community - in combination with dedicated detector systems, which have been built and which are operated by international collaborations.  

The physics program at COSY focusses on the following key topics:
- Symmetries and symmetry breaking in hadron physics;
- Hadron spectroscopy and reactions;
- Spin physics and spin dynamics in storage rings.  

IKP is committed to research and development for the FAIR project at Darmstadt as one of its major future activities; several key issues are/will be investigated and tested at COSY:
- High energy electron cooling and stochastic cooling techniques;
- Beam-target interactions using a pellet target and energy loss compensation techniques;
- Spin-filtering method to produce polarized beams.  

In addition, substantial contributions of IKP towards the realization of FAIR include:
- Design, construction and operation of the High Energy Storage Ring (HESR) for antiprotons as the leading laboratory;
- Development and installation of the PANDA detector at HESR as a major institution.  

As a new project, IKP is pursuing research and development for a charged-particle EDM search (JEDI, Jülich Electric Dipole moment Investigations), which in a first step should lead to a precursor experiment at COSY for protons and deuterons and later to a dedicated EDM storage ring.
Technical facilities:

Characterization of the facility:

Few-GeV synchrotron for phase-space cooled and polarized proton and deuteron beams, internal and external detector systems and (polarized) targets.
Facility parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring length</td>
<td>184 m</td>
</tr>
<tr>
<td>Momentum range</td>
<td>0.27 – 3.7 GeV/c</td>
</tr>
<tr>
<td>Particle species</td>
<td>p, d (vector and tensor polarized)</td>
</tr>
<tr>
<td>Beam intensity</td>
<td>Up to ~10^{11}</td>
</tr>
<tr>
<td>Cooling methods</td>
<td>electron, stochastic</td>
</tr>
<tr>
<td>Internal experiments</td>
<td>ANKE, WASA</td>
</tr>
<tr>
<td>External experiments</td>
<td>COSY-TOF (up to 2013)</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility's major instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Name of experiment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANKE</td>
<td>&quot;Apparatus for the detection of Nuclear and Kaon Ejectiles&quot;&lt;br&gt;Dipole spectrometer with acceptance in forward direction&lt;br&gt;Special range telescopes optimized for K+ meson detection</td>
</tr>
<tr>
<td>WASA</td>
<td>&quot;Wide Angle Shower apparatus&quot;&lt;br&gt;Spectrometer for charged and neutral particles comprising a superconducting solenoid and a CsI(Na) calorimeter</td>
</tr>
<tr>
<td>COSY-TOF</td>
<td>&quot;Time-of-Flight spectrometer&quot;&lt;br&gt;Large acceptance, non-magnetic spectrometer</td>
</tr>
<tr>
<td>PAX</td>
<td>&quot;Polarized Antiproton Experiment&quot;&lt;br&gt;Detector system for polarizing (anti-) protons by spin filtering</td>
</tr>
</tbody>
</table>

User facility: Yes.

Program Advisory Committee/Experiment Proposals: Yes.

Number of actual, active users of the facility in a given year: 450 (users listed on collaboration lists or proposals in 2013)

Percentage of users, and percentage of facility use that come from inside the institution: 18 % from FZJ

Percentage of national users: 34 % (including FZJ users)

Percentage of users from outside the country where your facility is located: 66 %

Fraction of international users outside of geographical region: 33 % (non European)

User group:
CANU (COSY Association of Networking Universities), 125 members

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
 a) 125, b) 23

Number of theoretical staff employed at the facility (permanent, postdoctoral, students):
8 permanent, 1 postdoctoral, 3 graduate students, 2 undergraduate

Number of postdoctoral researchers: 7

Number of graduate students resident at the facility: 16

Number of non-resident graduate students with thesis work primarily done at the facility: 10

Involvement of undergraduate students in research (approximate average number at a given time): 8

Special student programs:
Hadron physics summer school (together with ELSA / University of Bonn)
Lectures and seminars at universities (Aachen, Bochum, Bonn, Cologne, Wuppertal)

Future Plans:
High-energy (2 MV) electron cooler commissioning (2014);
Siberian snake for longitudinal spin-filtering(2014);
Precursor charge-particle EDM search (2015 and beyond), which may lead to a dedicated storage ring EDM project involving COSY.
FORSCHUNGSNEUTRONENQUELLE HEINZ MAIER-LEIBNITZ
FRM II (GERMANY)

FRM II
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Telephone: +49 89 289 149 65
http://www.frm2.tum.de

Telephone: +49-89-289-10703
Facsimile: +49-89-289-10799
E-mail: userinfo@frm2.tum.de

University institute of Technische Universität München
The free state of Bavaria and Federal Republic of Germany,
European Union

Prof. Dr. Winfried Petry, Director

Head of facility (IKP):

Prof. Dr. Winfried Petry
email: winfried.petry@frm2.tum.de
phone: ++49-89-289-14704
fax: ++49-89-289-14995

Facility:
The FRM II is a high neutron flux research reactor. It provides a broad spectrum of user dedicated facilities with a focus on solid state physics and fundamental physics. Currently a new source for ultra cold neutrons and a high flux cold neutron beam for nuclear and particle physics are under construction. Both will be open for external users.

Technical Facilities:
PGAA: prompt gamma activation analysis, nuclear spectroscopy
NEPOMUC: high intense monochromatic positron source, special beamport for nuclear physics.
MEPHISTO: cold white neutron source for nuclear and particle physics experiments.
UCN: ultra cold neutron source (under construction), neutron electric dipole moment, neutron lifetime, gravitational effects

**Characterization of the facility:**
Neutron high flux research reactor with a core flux of \(8 \times 10^{14}\) neutrons \(\text{cm}^{-2}\text{s}^{-1}\) at 20 MW thermal power.

**Facility Parameters:**
The thermal neutron spectrum (\(T=300\text{K}\)) is remoderated on certain beam tubes with a cold source (\(T=25\text{K}\))

**Major experimental instrumentation and its capabilities:**
The complete instrumentation (including nuclear and particle physics) can be found on the webpage [www.frm2.tum.de](http://www.frm2.tum.de)

**Nature of facility:**
The facility is an official user facility. 66 % of the beam time at the instruments is dedicated to external proposals.

**Program Advisory Committee/Experiment proposals:**
Five scientific program advisory committees (evaluation of beamtime proposals)

**Percentage of users from national users, from outside of geographical region:**
5% North America; 1% Asia; 2% Australia (database user office)

**Percentage of users, and percentage of facility use that come from inside the institution:**
2008: 28% users 34 % beamtime (database user office)

**Percentage of users and percentage of facility use from national users:**
2008: 39 % users 34 % beamtime (database user office)

**Percentage of users and percentage of facility use from outside the country where the facility is located:**
2008: 33 % users 32 % beamtime (database user office)

**User group:**
No

**Number of a) permanent staff and b) temporary staff (incl. graduate students and postdoctoral researchers):**
a) 1  
b) 4

**Number of theoretical staff employed at the facility:**
0

**Number of postdoctoral researchers:**
2 scientists on the facility payroll, 1 scientist from external institute

**Number of graduate students resident at the facility (> 80% of their time):**
5 students

**Number of non-resident graduate students with thesis work primarily done at the facility:**
2

**Involvement of undergraduate students in research:**
6

**Special student programs:**
Lectures and seminars on different levels about nuclear physics are held at the physics department of Technische Universität München (on campus)

**Future plans:**
The main project in the next years will be the installation of a ultra cold neutron source (UCN) in the new east experimental hall. In addition the cold neutron beam line MEPHISTO will be relocated also in this new hall.
The facility is situated in the north of Munich. It can be reached well by underground The U6 connects the city centre directly with "Garching Forschungszentrum".
The Munich international airport is located nearby and accessible via suburban trains and buses.
Heads of facility:
Prof. Dr. Horst Stöcker – Scientific Director
Mr. Peter Hassenbach – Administrative Director

Scientific Mission and Research Programs:
GSI's mission is the development, construction and operation of ion beam accelerators for a broad national and international science community and doing research with heavy ions. GSI operates a large accelerator complex consisting of the linear accelerator UNILAC, the heavy-ion synchrotron SIS and the experiment storage-cooler ring ESR. Ions of all elements, from hydrogen to uranium, can be accelerated up to energies of 1-2 AGeV, highly ionized up to bare uranium, and secondary beams of unstable nuclei or secondary pions are available. The accelerators are complemented by technically advanced experimental facilities as well as a high-energy (kJ), high power (PW) laser system Phelix, which altogether offer outstanding opportunities for research in the fields of hadron and nuclear physics, atomic physics, dense plasma research, material science, biophysics and radiation medicine.

During the next years until 2018/19 the major mission of GSI will be the construction of the international Facility for Antiproton and Ion Research (FAIR) together with national and intern partner institutions.

As a consequence, the operation time of the GSI facilities will be dramatically reduced and there will be only very limited user time available until 2017.

Technical facilities (note that only limited operation times will be offered during the next years due to the construction of the FAIR facility on the GSI premises):
Characterization of the facility:

The GSI accelerator complex provides ion beams of all stable elements up to uranium with energies from the Coulomb barrier up to 2 AGeV. In addition, secondary beams of unstable nuclei are available as well as beams of highly ionized atoms up to bare uranium and beams of secondary pions. As a further option, secondary pion beams can be delivered at momenta of 0.5 GeV/c to 2.5 GeV/c. Several experiments can be performed in parallel, using different ions.

UNILAC, a 120m linear accelerator, provides intense ion beams (p to U) at energies up to 11.4 AMeV. The UNILAC serves as an injector to the synchrotron SIS.

SIS, the heavy-ion synchrotron with 216m circumference and a maximum bending power of 18 Tm accelerates particles of p to U up to 2 AGeV.

FRS, a 75m Projectile Fragment Separator, provides unstable isotopes of all elements up to uranium.

In the ESR (experimental storage ring), stable or radioactive ion beams can be stored and cooled at energies up to 0.56 AGeV (for U).

The pion-beam facility provides pion-beams in the momentum range of 0.5 to 2.5 GeV/c.
Table of facility parameters:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Particle</th>
<th>Energy Range</th>
<th>Charge (expl.)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNILAC - heavy ion linear accelerator</td>
<td>p to U</td>
<td>1.4-12 AMeV</td>
<td>10 uA</td>
<td>粒子范围为1.4-12 AMeV，电流为10微安。</td>
</tr>
<tr>
<td>SIS 18 - heavy ion synchrotron, magnetic rigidity 18 Tm, cycle rate 1Hz</td>
<td>p to U</td>
<td>10 – 4500 AMeV (p); heavy ions: 10-1000 AMeV</td>
<td>Ne10+ Ar10+ U73+</td>
<td>Ne10+, Ar10+, U73+粒子，每循环周期为0.7 AGeV, 8<em>10^10 ions/cycle, 3</em>10^9 ions/cycle; 有机会在注入能量下对电子冷却。</td>
</tr>
<tr>
<td>ESR - heavy ion storage ring, magnetic rigidity 10 Tm</td>
<td>p to U</td>
<td>for U up to 560 AMeV (HITRAP: 4 AMeV)</td>
<td>Electron-, fast stochastic and laser cooled ions; interaction with internal gas targets</td>
<td></td>
</tr>
<tr>
<td>Pion-beam facility</td>
<td>pion-beam</td>
<td>momentum range: 0.5-2.5 GeV/c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phelix laser</td>
<td>laser beam</td>
<td>high-energy (kJ), high power (PW) laser system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brief and compact table with the facility's major experimental instrumentation and its capabilities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Instrument</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-------------------</td>
<td>-------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HADES</td>
<td>High Acceptance Di-Electron-Spectrometer</td>
<td>for studying the properties of vector mesons in high density hadronic matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRS - fragment separator</td>
<td>large projectile fragment separator</td>
<td>allowing the production and in-beam separation of nuclei far off stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R³B</td>
<td>Relativistic Radioactive Reaction Experiment</td>
<td>to study high-lying collective states and complete kinematics break-up reactions of exotic nuclei</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHIP spectrometer</td>
<td>velocity filter</td>
<td>separation and detection of super-heavy elements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHIPTRAP</td>
<td>Penning trap</td>
<td>for nuclear structure and atomic physics studies on very heavy nuclei/atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HITRAP</td>
<td>ion trap</td>
<td>for atomic physics and nuclear structure studies on heavy, highly-charged ions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TASSCA</td>
<td>Transactinide separator and chemistry apparatus</td>
<td>to study single ion chemistry of super heavy ions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESR</td>
<td>cooler storage ring</td>
<td>equipped with: Schottky mass spectroscopy; time-of-flight mass spectroscopy using the isochronous operation mode of the ring; internal gas-jet target and detector system; various X-ray and position sensitive particle detectors; collinear laser spectroscopy system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHELIX</td>
<td>high power, high energy laser</td>
<td>for plasma physics experiments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two experimental stations for dense plasma research</td>
<td></td>
<td>allowing the combined application of intense ion and PHELIX laser beams for plasma generation and diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-branch</td>
<td>three beamlines for materials research with in situ characterization of irradiated samples (SEM, XRD, FTIR, UV-Vis, RGA, etc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XO-beamline</td>
<td>up to UNILAC energies, broad fluence regime (single ion up to 1e14 cm^-2), efficient sample exchange system, cryostage (5 K)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy-ion microprobe</td>
<td>up to UNILAC energies, precision irradiation experiments with pre-defined number of ions (spatial resolution of ~1 μm) and exposure of biocells in medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-purpose experiment stations (SIS energies) for atomic physics, material science and radiation biology research</td>
<td>equipped with, e.g., a charge-state separator/analyser for atomic reaction products, a raster scanner for vertical and horizontal beam deflection (20x20 cm^2), irradiation of samples in high-pressure cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector test facility</td>
<td>for detector tests, beams of protons, ions, pions and electrons can be provided.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nature of user facility:

With about 1500 users p.a., GSI in the past years de facto was a user facility for the international science community. In the coming years preceding the start of the FAIR facility, user operation will be offered.
strongly reduced due to the construction of the FAIR facility on the GSI premises.

**Program Advisory Committee/experiment proposals:**

To cover the broad spectrum of research pursued at GSI, four program advisory committees with external scientists have been established for the different fields:

(i) The General Program Advisory Committee (G-PAC) addressing the research fields nuclear physics and atomic physics, acting as central PAC.

(ii) PHELIX and Plasmaphysics Advisory Committee (Phelix Committee)

(iii) Biophysics and Radio-Biology Program Advisory Committee (Bio-PAC)

(iv) Materials Research Program Advisory Committee (Mat-PAC)

**Percentage of users from national users, from outside of geographical region:**

From an analysis of the number of users contributing to the GSI Annual Report over the recent years, one finds:

- **Total number of users:** ca. 1500
  - internal users ca. 15%
  - other national users ca. 45%
  - international users ca. 40%
  - European (w/o German users) ca. 30%
  - outside Europe ca. 10%

**User group:**

The GSI User Group has 1,150 registered subscribers (as of Sept. 2013).

**Number of a) permanent staff and b) temporary staff (incl. graduate students and postdoctoral researchers):**

- Permanent staff: 770
- Temporary staff: 780

**Number of theoretical staff employed at the facility:**

- Permanent: 3
- Temporary: 5

**Number of postdoctoral researchers:**

In 2012, there were about 55 scientists on postdoc positions at GSI.

**Number of graduate students resident at the facility (> 80% of their time):**

In 2012, approx. 125 PhD students performed their thesis work directly at GSI.

**Number of non-resident graduate students with thesis work primarily done at the facility:**

In addition, about 250 PhD students worked on research topics at GSI and in neighbouring universities.

**Special student programs:**

International Summer Student Program (8 weeks in late summer): about 40 undergraduate students from all over the world.

School Laboratory 'Radioactivity and Radiation' for high school students: In 2012, about 2100 high school students visited the school lab.

Saturday Morning Physics (every fall): series of lectures on modern physics for high school students including a tour of the GSI facilities (together with the Technical University Darmstadt).

Lectures on and guided tours of GSI: In 2012 about 5230 non-scientific visitors had guided tours at GSI.

Girl's-day (one-day visitor program for girls): in 2013, about 30 girls participated in the Girl's day.

Two-week to four-week internships for high school and undergraduate students: ca. 90 students in 2013.

**Future plans:**

The international FAIR facility, a project of several international partners, will offer relativistic beams of antiprotons as well as of stable and unstable heavy ions combined with sophisticated instrumentation. Energies up to 35 GeV/u are foreseen and an intensity gain compared to the present GSI facility of a factor of 100 for stable and 10,000 for rare isotopes.

A superconducting double-synchrotron SIS100/300 with a circumference of about 1,100 meters and with magnetic rigidities of 100 and 300 Tm, respectively, is at the heart of the FAIR accelerator facility. Following an upgrade for high intensities, the existing GSI accelerators UNILAC and SIS18 will serve as an injector. Attached to the large double-synchrotron SIS100/300 is a complex system of storage-cooler rings and experiment stations including a superconducting nuclear fragment separator (Super FRS) and an antiproton
production target. Due to the intrinsic cycle times of
the accelerator and storage-cooler rings, up to four
research programs can be run in a truly parallel
mode. This allows, in a very efficient and cost-
effective way, a rich and multidisciplinary research
program to be conducted covering a broad spectrum
of research fields such as: QCD studies with cooled
beams of antiprotons; QCD-Matter and QCD-Phase
Diagram at highest baryon density; nuclear structure
and nuclear astrophysics investigations with nuclei
far off stability; precision studies on fundamental
interactions and symmetries; high density plasma
physics; atomic and material science studies; radio-
biological investigations and other application
oriented studies. Full operation of the FAIR facility
is scheduled for 2018.
MAIER-LEIBNITZ-LABORATORY FOR NUCLEAR -, PARTICLE AND ACCELERATOR PHYSICS OF THE TU MÜNCHEN AND THE LMU MÜNCHEN

GARCHING-MLL (Germany)

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Germany
Email: MLL@LMU.de
http://www.bl.physik.tu-muenchen.de/

Joint University Institute
of the Technische Universität München and Ludwig Maximilians Universität München

Operation and investment funds by the State of Bavaria
Various research grants from federal ministry (BMBF), German Research Association (DFG), European Union (EU), Bavarian Research Foundation

Prof. Dr. Stephan Paul
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Head of facility:
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Telephone: +49-89-289-14271
Facsimile: +49-89-289-14280

Scientific Mission and Research Programs:
The Maier-Leibnitz-Laboratory (MLL) for Nuclear-, Particle, and Accelerator Physics of both Munich universities supports activities over a broad range of experimental and theoretical research subjects from Elementary Particle Physics, Particle Astrophysics, Nuclear and Hadron Physics, Laser Acceleration as well as Applied Nuclear Physics. MLL researchers carry out experimental work at the local facilities as well as at major international facilities, such as CERN, GSI Darmstadt, Gran Sasso, and Fermilab as well as various smaller facilities. The MLL operates a 14 MV tandem accelerator, a large cosmic ray test stand for ATLAS muon chambers and a underground laboratory for the development of cryogenic detectors as well as workshops and technological laboratories. The MLL currently constructs a source for ultra cold neutrons and a high power laser facility for the production of high energy beams of photons and ions.
Technical facilities:

Characterization of the facility:

The electrostatic 14 MV MP tandem accelerator of the MLL provides a broad range of light and heavy ion beams for national and international users working in the areas of nuclear structure physics, nuclear astrophysics, and applied nuclear physics. Beam can be delivered to 17 different experimental stations.

Table of facility parameters:

A broad range of beams from H to U including polarised p and d, DC or bunches of down to 1 ns with frequencies of 5 MHz are available. The following table provides exemplary information, where the intensity relates to the highest energies.
<table>
<thead>
<tr>
<th>Element</th>
<th>Max. Intensity</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>p,d (polarized)</td>
<td>2 µA</td>
<td>28 MeV</td>
</tr>
<tr>
<td>6,7Li</td>
<td>270 nA</td>
<td>56 MeV</td>
</tr>
<tr>
<td>12,13C, 16-18O</td>
<td>3 µA</td>
<td>98,126 MeV</td>
</tr>
<tr>
<td>40-48Ca</td>
<td>720 nA</td>
<td>196 MeV</td>
</tr>
<tr>
<td>58-64Ni</td>
<td>230 nA</td>
<td>224 MeV</td>
</tr>
<tr>
<td>107Ag</td>
<td>10 nA</td>
<td>266 MeV</td>
</tr>
<tr>
<td>112-124Sn</td>
<td>10 nA</td>
<td>266 MeV</td>
</tr>
<tr>
<td>197Au</td>
<td>70 nA</td>
<td>266 MeV</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:

- Q3D magnetic spectrograph with various light and heavy ion detectors.
- SNAKE (Superconducting Nanoscope for Applied nuclear (Kern-)physics Experiments)
- Ge gamma-ray detectors and conversion electron spectrometer
- Gas filled magnet for AMS
- High resolution Penning Trap
- Neutron scattering facility
- Shielded laboratory for low-background experiments

Nature of user facility:
The MLL tandem laboratory is an unofficial user facility for national and international users.

Program Advisory Committee/experiment proposals:
Beam time for proposed experiments is distributed by an in house user committee.

Number of active users and their origin:
120

Percentage of users, and percentage of facility use that come from inside the institution:
inside users: 31%,
inside usage: 100%, because always inside users are always involved

Percentage of users and percentage of facility use from national users:
national users: 75%
national usage: also 100%

Percentage of users and percentage of facility use from outside the country where your facility is located:
international users: 25%,
international usage: approximately 50%

Fraction of international users outside of geographical region:
about 4% non-European users

User Group:
no formal users group

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
a) permanent staff: 14 in the facility itself, 6 each in the physics departments of TUM and LMU
b) temporary staff: 32

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
no theoretical staff directly at the facility but part of the MLL

Number of postdoctoral researchers:
12

Number of graduate students resident at the facility:
15

Number of non-resident graduate students with thesis work primarily done at the facility:
5

Involvement of undergraduate students in research:
10

Special student programs:
An experiment at the tandem accelerator is performed every semester as part of the advanced laboratory courses of both participating universities.

Future plans:
Two new major infrastructures are in the planning or construction phase
- UCN: intense source for ultra-cold neutrons at the FRM II for EDM and neutron half-life measurement is under construction
- Center for Advanced Laser Applications: High power laser facility for production of high energy photon and ion beams by means of laser acceleration is in planning phase
MAINZ MICROTRON (MAMI)

Mainz, Germany

Institut für Kernphysik
Johannes Gutenberg-Universität Mainz
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D-55099 Mainz

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Telephone: +49 6131 39-25802
Facsimile: +49 6131 39-22964
E-mail: sfienti@kph.uni-mainz.de

Main sources of funding: Collaborative Research Centre SFB1044 of the German Research Foundation (DFG), Excellence initiative PRISMA, University of Mainz, and Federal State of Rhineland-Palatinate

Head of the facility:
Acting Director: Prof. Dr. Concettina Sfienti

Scientific Mission and Research Programs:
Study of the structure of hadrons with electromagnetic probes at low energies and momentum transfers. Precision studies of light nuclei and hypernuclei.

Technical facilities:

Picture of the Institut für Kernphysik and the MAMI accelerator. (in front MAMI control room (left) and spectrometer building (right).
Characterization of the facility:
Cascade of four race track microtrons with c.w. polarized electron beam. Secondary real photon beam. A new, energy-recovering, superconducting linac (MESA) is under construction.

Table of facility parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam species</td>
<td>e−</td>
</tr>
<tr>
<td>Energy range</td>
<td>180 – 1604 MeV</td>
</tr>
<tr>
<td>Maximum current</td>
<td>100 µA</td>
</tr>
<tr>
<td>Beam Polarization</td>
<td>80%</td>
</tr>
<tr>
<td>Horizontal Emittance</td>
<td>$12 \times 10^{-6} \pi \cdot m \cdot \text{rad (1σ)}$</td>
</tr>
<tr>
<td>Vertical Emittance</td>
<td>$1.7 \times 10^{-6} \pi \cdot m \cdot \text{rad (1σ)}$</td>
</tr>
<tr>
<td>Secondary Beam</td>
<td>tagged photon beam</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:

A1 (electron scattering): Setup of three high resolution magnetic spectrometers, one is equipped with a proton polarimeter. Short orbit spectrometer for pion detection. Short orbit, high magnetic field kaon spectrometer. Calorimetric detector for nucleons, time-of-flight walls for neutron detection. Liquid hydrogen/deuterium/helium target, polarized $^3\text{He}$ target.

A2 (real photon scattering): Tagged photon beam with unpolarized and polarized photons. Large solid angle detector Crystal Ball/TAPS. Liquid H$_2$, D$_2$, $^3\text{He}$ targets, and a polarized frozen-spin target for polarized protons and deuterons.

A4 (parity violating electron scattering): Previous setup of fast PbF$_2$ crystal detectors with high count rate readout electronics and high power liquid hydrogen/deuterium target, to be continued at MESA.

X1 (X-ray generation): Coherent X-ray generation using transition and undulator radiation and the Smith-Purcell effect.

Nature of user facility:
No. All access is through collaborative programs. For access, external scientist should contact the collaborations directly (see instrumentation).

Program Advisory Committee/experiment proposals:
Yes. Submission of written proposals, followed by oral presentation to a Program Advisory Committee. 1 national and 7 international members.

Number of active users and their origin:
Average 160 users.

Percentage of users, and percentage of facility use that come from inside the institution:
50% (estimate)
Percentage of users and percentage of facility use from national users:
50% (estimate)

Percentage of users and percentage of facility use from outside the country where your facility is located:
30% (estimate)

Fraction of international users outside of geographical region:
20%

User Group:
No.

Total number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
a) permanent: 13 Prof., 26 scient., 80 tech./administr.
b) temporary: 115

Number of theoretical staff employed at the facility: permanent, postdoctoral, students:
6 (permanent), 8 (postdoctoral), 14 (students)

Number of postdoctoral researchers:
35

Number of graduate students resident at the facility:
90

Number of non-resident graduate students with thesis work primarily done at the facility:
10 (estimate)

Involvement of undergraduate students in research (approximate average number at a given time):
20 (estimate)

Special student programs:
Several student programs are organized by the University of Mainz. The facility is integrated in the physics education of the University, e.g. in the context of advanced laboratory courses. High school internships are possible at all stages. Research Training Group (Graduiertenkolleg) of the DFG. Annual SFB and PRISMA Student Summer Schools.
TANDEM ACCELERATOR  
UNIVERSITY OF COLOGNE

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Facsimile: +49 221 470 5168  
E-mail: dewald@ikp.uni-koeln.de  
Web Address: www.ikp.uni-koeln.de

University Institute

Various sources of funding:  
Initial funding: Land Nordrhein Westfalen, Bundesministerium für Bildung und Forschung  
Staffing and Operation: Internal University funds  
Instruments and development: Internal University funds,  
Deutsche Forschungsgemeinschaft (DFG), Hochschulbau Förderungs Gesetz (HBFG),  
Bundesministerium für Bildung und Forschung (BMBF)

Heads of the facility:

The facility is operated by the Institut für Kernphysik.  
Director: Prof. Dr. J. Jolie  
Facility operation Manager: Dr. A. Dewald

The FN Tandem Accelerator is one of the largest instruments of the University of Cologne. This accelerator was installed in 1969 and has, over the decades, been continuously innovated and improved and is still a state-of-the-art facility for university based research. While the Tandem Accelerator has been pushed to its limits with the terminal voltage reaching 10 MV, one of the cornerstones of the Institute is the development of new experimental methods and the increased sophistication of detectors, ion sources and data analysis. The facility is mainly used for the study of low-spin excited states at high excitation energy. It forms the core of the Institute’s education and research.

The current research program uses:

- sub Coulomb barrier reactions,  
- Coulomb excitation,  
- light-ion induced fusion evaporation reactions,  
- proton induced X-ray emission,  
- ion implantation

for the study of:

- symmetries in nuclear structure  
- (isospin, F- spin, dynamical symmetries and supersymmetries,  
- collective and chaotic behaviour of yrare states,  
- shape phase transitions and shape coexistence,  
- shell effects,  
- applied physics.

Three ion sources (a duoplasmatron and two sutter sources) produce a variety of different ions (see Table 1). The beam can be bunched down to ns short pulses. The eight beamlines are equipped with different instruments. The most important ones are:

The HORUS spectrometer which is a compact cube Ge array with 14 60-80% Ge
detectors. It is equipped with a beta-slider and ideally suited for DCO measurements;

The MINIBALL beamline which is equipped for particle gamma coincidences and often hosts the MINIBALL array.

The ORANGE spectrometer for conversion electron spectroscopy which can be used for $e^-\gamma$ coincidences;

The COLOGNE PLUNGER set-up for lifetime measurements;

The PIXE set-up with a swept beam.

Figure 1 shows an overview of the accelerator and its beamlines. As well as the accelerator, a well equipped target laboratory is available. The facility is informally run as a user facility without a PAC; requests for beam time can be sent to the director or the responsible. Beamtime is distributed about every six weeks. The accelerator has about 45 in-house users, mainly students (14), PhD students (20), post-docs (4) and permanent staff (8). The number of external national users is 20 and of international users 25, of which about 5 from the USA. Most of the time, experiments are performed in collaborations with the different users. The accelerator is operated with a dedicated technical staff of three persons and the in-house students, PhD students and post-docs. Students are taught how to run the machine as part of their education. The facility runs 24 hours a day and also over the weekends, typically 5000-6000 hours a year.

<table>
<thead>
<tr>
<th>Beam Species</th>
<th>Max. Energy Single Stripping</th>
<th>Beam Species</th>
<th>Max. Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>20</td>
<td>$^{24,25,26}$Mg</td>
<td>110</td>
</tr>
<tr>
<td>$d$</td>
<td>20</td>
<td>$^{27}$Al</td>
<td>120</td>
</tr>
<tr>
<td>$^{3,4}$He</td>
<td>30</td>
<td>$^{28,29,30}$Si</td>
<td>120</td>
</tr>
<tr>
<td>$^{6,7}$Li</td>
<td>40</td>
<td>$^{31}$P</td>
<td>120</td>
</tr>
<tr>
<td>$^{10,11}$B</td>
<td>50</td>
<td>$^{32,33,34}$S</td>
<td>120</td>
</tr>
<tr>
<td>$^{12,13}$C</td>
<td>70</td>
<td>$^{46,47,48,49}$Ti</td>
<td>120</td>
</tr>
<tr>
<td>$^{14,15}$N</td>
<td>80</td>
<td>$^{50,52,54}$Cr</td>
<td>120</td>
</tr>
<tr>
<td>$^{16,18}$O</td>
<td>90</td>
<td>$^{58,60}$Ni</td>
<td>130</td>
</tr>
<tr>
<td>$^{19}$F</td>
<td>90</td>
<td>$^{63,64}$Cu</td>
<td>130</td>
</tr>
<tr>
<td>$^{23}$Na</td>
<td>90</td>
<td>$^{81}$Br</td>
<td>130</td>
</tr>
</tbody>
</table>

Table 1: Examples of available beams.

Figure 1: The Tandem accelerator and experimental facilities (see text).
ATOMKI is one of the research institutes of the Hungarian Academy of Sciences. At present it employs 197 persons. The Academy is a public body, and Atomki is a non-profit institution relying on the state budget and on the national and European science funding systems. In its technological innovative activity and laboratory services provided to authorities and industry it is in contractual relationship with other public organizations and business firms. The institute was meant to pursue scientific research in certain areas of experimental nuclear physics and to develop research instruments. The institute has become the main center of accelerator based nuclear and atomic physics in Hungary.

Roughly 60% of the activity goes to basic research. 35% of the research is nuclear physics, 25% is atomic physics, 15% is environmental physics, 15% applied physics and 10% is development of techniques and instruments for basic and applied research.

Accelerators:

http://www.atomki.hu/Accelerators/index_en.html

Isochronous cyclotron (K=20) for light ions, p,d, $^3$He, $\alpha$ and intensities of maximum 50 µA. Energies from 3 MeV (p) to 27 MeV for $^3$He particles.

**Related main facilities:**

- Neutron sources
- B-type radiochemistry laboratory

Energy spread of extracted beam: < 3*10$^{-3}$
Energy spread of analyzed beam: < 10$^{-3}$
External target locations: 8 horizontal, 1 vertical

**Main Instrumentation for Nuclear Physics Experiments:** Split pole magnetic spectrograph. CLOVER type HPGe detector with BGO shield and other HPGe detectors. Superconducting Solenoid and mini orange magnetic electron spectrometers. Ionization chambers and PPAC detectors for fission fragments. Scattering chamber with Si particle telescopes. Multidetector array for high energy nuclear $e^+e^-$ pair spectroscopy.

**1 MV Van de Graaff accelerator**

Ions: H$^+$, He$^+$, C$^+$
Max. current: 1-20 µA
Nominal voltage: 1 MV
Energy stability: <1 kV
5 MV Van de Graaff accelerator
Ions: H+, D+, He+, C+, N+, O+, Ne+
Max. current: 1-20 µA
Nominal voltage: 5 MV
Energy stability: <1 kV

The accelerator provides light ion beams of typically 1-4 MeV to users of atomic physics, nuclear physics, and Ion Beam Applications (ion beam analysis and micromachining). The IBA work is performed on various fields ranging from environmental research, through materials science, to biomedical applications.

Main instrumentation:
PIXE chamber, Scanning Ion Microprobe (based on Oxford Microbeams). Detectors: Retractable X-ray detectors with Super Ultra Thin Window (SUTW) and dura Be window (FWHM=136 eV), particle detection by Si PIPS detectors and PIN diodes, gamma-ray detection by Clover-Ge-BGO detector system. NRA (PIGE/DIGE), external beam setup, electron spectrometers and a magnetically shielded scattering chamber for atomic collision experiments.

AMS facility
Since 2011 an accelerator-mass-spectrometry (AMS) facility has been operating for C-14 measurements and dating from small samples (1-0.01 mg C) at large rate (1 sample an hour) and at large precision (relative error <0.3%).

The accelerators and detectors are user facilities. A Program Advisory Committee decides about the experimental proposals: http://www.atomki.hu/PAC/index_en.html

Informal user group:
40
Inside users:
28 (70 %)
National users:
7 (18 %)
International users:
5 (12 %)
Theoretical staff:
8
Postdoctoral researchers:
3
Graduate students:
4
Future Plans:
In 2013 we started the complex process of purchasing and installing a new 2 MV (High Voltage Eng.) tandetron type accelerator. This new accelerator is devoted to produce proton beams upto 4 MeV energy with excellent energy stability and with minimum demands for maintenance.
EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS (ECT*)

TRENTO ECT* (Italy)

Strada delle Tabarelle, 286
I-38123 Villazzano (Trento)

Telephone: +39 0461 314 722
Facsimile: +39 0461 920164
E-mail: susan@ect.it
www: http://www.ectstar.eu

Wolfram Weise, Director
Telephone: +39 0461 314 760
E-mail: weise@ectstar.eu

Local funding (FBK), European contracts, funding through international agencies.

Heads of the facility:
Professor Wolfram Weise

Facility:
ECT* hosts a variety of activities in theoretical nuclear physics and related areas: workshops and collaboration meetings, doctoral training programs, innovative research. It offers positions for postdoctoral fellows and visiting scientists. It has two dedicated clusters for parallel computing. ECT* is an institutional member of the ESF Committee NuPECC.

Technical facilities:
Offices in two buildings: Villa Tambosi and the Rustico; two conference rooms (capacities of 40 and 80). The ECT* staff finds accommodation for visiting scientists and postdoc researchers in local hotels, apartments and university residences.

Programme Advisory Committee (current membership):
The ECT* Scientific Board. The current members are: B. Balantekin (Chair), A. Bracco, F. Gélis, J. McGovern, P.H. Heenen, M.P. Lombardo, P. Mulders, A. Polls and J. Stachel.

Main Instrumentation for Nuclear Physics Experiments:
- Workshops and collaboration meetings
- Doctoral Training Programme
- Positions for postdocs and visiting scientists
- In-house library and access to the Physics Department library

Main Fields of Nuclear Research:
Nuclear structure and low energy nuclear physics, QCD and hadron physics, high energy heavy ion reactions, nuclear matter under extreme conditions, nuclear astrophysics.
Main Fields of Other Research:
Related Areas: Particle physics, astrophysics, condensed matter physics and quantal physics of small systems, quantum information.

Number of active users and their origin:
Approx. 700 users per year from about 40 countries worldwide.

User group:

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
2013:
Permanent staff: 7, postdoctoral researchers: 8.

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
2013: 8 postdoctoral researchers, 1 Director, (total theoretical staff: 9 + 22 graduate students during three months)

Number of graduate students resident at the facility:
Graduate students are resident at ECT* during the “ECT* Doctoral Training Programme”, that takes place once a year and has a duration of approx. 3 months. In 2013: 22 graduate students participated in the Training Programme.

Involvement of undergraduate students in research (approximate average number at a given time):
Approx. 10.
LABORATORI NAZIONALI DEL GRAN SASSO
ASSERGI LNGS (ITALY)

Istituto Nazionale di Fisica Nucleare
S.S. 17 bis, km.18+910
67010 Assergi (L’Aquila)

Telephone: +39 08 62 43 71
Facsimile: +39 08 62 43 72 18
WWW: http://www.lngs.infn.it

Eugenio Coccia, Director
Telephone: +39 08 62 43 72 31

Contact Person for Foreign Users

M. Junker (LUNA)
E-mail: matthias.junker@lngs.infn.it
M. Laubenstein (Low Level Laboratory)
E-mail: matthias.laubenstein@lngs.infn.it
F. Chiarizia (Research Division Secretary)
E-mail: fausto.chiarizia@lngs.infn.it

Facility:
50 kV and 400 kV accelerators (LUNA) with very small energy spread, excellent long term stability and high beam current even at low energy. Ultra low radioactivity levels laboratory.

Procedure to Apply for Beamtime:
All proposals are screened on the basis of scientific merit by the LNGS Scientific Committee.

Programme Advisory Committee (current membership):
0 in-house, 4 national, 5 international members.

Main Instrumentation for Nuclear Physics Experiments:
LUNA: 50kV and 400 kV electrostatic accelerators, windowless gas target, BGO summing detector and High Purity Germanium detector with low intrinsic background.

Main Fields of Nuclear Research:
Nuclear reactions of astrophysics interest.

Main Fields of Other Research:
Neutrino Physics.
Dark Matter Search.
Rare Decays.

Accommodation:
7 double rooms (14 beds).

Transportation:
Public Bus Service from and to L’Aquila every hour.

Future Developments (under construction):
Enlargement of the low background levels laboratory.
INSTITUTO NAZIONALE DI FISICA NUCLEARE
LABORATORI NAZIONALI DEL SUD

Via S. Sofia 62
95123 Catania, Italy
director@lns.infn.it

Telephone: +39 095 542111
Fascimile: +39 095 7141815

Government Institution
Government funds

Prof. Fernando Ferroni

**Head of the facility:**
Dott. Giacomo Cuttone
Designated Contact – Dott. Luciano Calabretta
CALABRETTA@LNS.INFN.IT
Telephone: 0039 095 542259
Fascimile: 0039 095 542300

**Scientific Mission and Research Programs:**
The scientific mission of the LNS is mainly the study of nuclear collisions at intermediate and low energy. Research activity in several multi-disciplinary (i.e. non-nuclear) fields is also developing. The current research program in nuclear physics is carried out with large detector systems ($4\pi$ multi-detector systems for the intermediate energy case) and a magnetic spectrometer with large acceptance both in solid angle and in momentum.
The current interdisciplinary research program concerns studies on Atomic Physics, Solid State Physics, Single Event Effects, Biology and Medicine, Dosimetry. The latter is mainly related to proton-therapy, which started in 2002 as a clinical activity.
In addition to the usual activities of production of stable beams, there are two main research programs:
- a short-range one is based on the use of radioactive ion beams produced with both the in-flight and Isol technique;
- A long-range research program, in the field of astro-particle physics, concerns the detection of astrophysical neutrinos by means of a deep under sea neutrino telescope (KM3net project).

**Technical facilities:**
Characterization of the facility:

Two accelerators, a Tandem Van De Graaff and a superconducting Cyclotron, deliver light and heavy-ion in the regions of low and medium energy.

EXCYT: a radioactive beam facility (ISOL-type) based on the Superconducting Cyclotron as primary accelerator and the Tandem as post accelerator.

FRIBs: a facility producing tagged secondary radioactive ion beams by in-flight fragmentation of the cyclotron primary beams.

Catana: a beam line dedicated to the treatment of eye melanoma using the 62 MeV proton beam delivered by cyclotron.

Facility Parameters:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Energy Range (AMeV)</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>4-28</td>
<td>&lt;1 pA – 1 µA</td>
</tr>
<tr>
<td>Deuterons</td>
<td>2-14</td>
<td>&lt;1 pA – 1 µA</td>
</tr>
<tr>
<td>He</td>
<td>-</td>
<td>&lt;1 pA – 0.3 µA</td>
</tr>
<tr>
<td>6,7Li, 9Be, 10,11B</td>
<td>1.5-8</td>
<td>&lt;1 pA – 0.3 µA</td>
</tr>
<tr>
<td>12,13C, 14,15N, 16,17,18O, 19F</td>
<td>1-8, 8-20</td>
<td>&lt;1 pA – 1 µA</td>
</tr>
<tr>
<td>20Ne, 24Ma</td>
<td>10-62</td>
<td>&lt;1 pA – 1 µA</td>
</tr>
<tr>
<td>27Al, 32S, 24S, 35,37Cl</td>
<td>0.9 – 6.5</td>
<td>&lt;1 pA – 10 nA</td>
</tr>
<tr>
<td>36,40Ar</td>
<td>1-4</td>
<td>&lt;1 pA – 40 nA</td>
</tr>
<tr>
<td>40,83Ca</td>
<td>10-40</td>
<td>&lt;1 pA – 5 nA</td>
</tr>
<tr>
<td>58,60Ni, 62,64Ni</td>
<td>0.5-3</td>
<td>&lt;1 pA – 5 nA</td>
</tr>
<tr>
<td>63,80Cu</td>
<td>0.7 – 5</td>
<td>&lt;1 pA – 5 nA</td>
</tr>
<tr>
<td>97Nb</td>
<td>0.5-1.5</td>
<td>&lt;1 pA – 5 nA</td>
</tr>
</tbody>
</table>

Cyclotron beams can be delivered with timing characteristics: peak width 1 ns FWHM and inter-burst distance 120-150 ns.

Major experimental instrumentation and its capabilities:

Main Instrumentation for Nuclear Physics Experiments

CHIMERA: a 4π charged particle detector, consisting of 1200 (Si + CsI) telescopes.

MEDEA + MULTICS: a BaF2 crystall ball of 180 elements for γ and light particle detection, coupled to a forward wall of 64 (gas chamber + Si + CsI) telescopes for fragment detection.

TRASMA: a multidetector suitable for simultaneous detection of particles and gamma rays.

CICLOPE: a cylindrical (4 m diameter, 6 m long) scattering chamber designed for intermediate energy experiments.

CT 2000: a 2m diameter multipurpose scattering chamber specially suitable for low energy experiments.

MAGNEX: a large solid angle and large momentum acceptance magnetic spectrometer.

Nature of user facility:
Yes, LNS is a user facility

**Program Advisory Committee/experiment proposals:**

The facility has a Program Advisory Committee which meets at least one time per year.

The PAC is composed of 2 nationals and 5 foreign members.

**Number of actual, active users of the facility in a given year:**

290 is the average over the last two years

This is the number of people who participate at experiments according to the access cards.

**Percentage of users and percentage of facility use from national users:**

National users 61%, facility used by national users 70%

**Percentage of users and percentage of facility use from outside the country where your facility is located:**

Foreign users 39%, facility use 29%

**Fraction of international users outside of geographical region**

10%

**User Group:**

About 330

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**

Permanent staff: 28 scientists + 19 associated University professors + 78 Technical staff

Temporary staff: 8 scientist +23 technical

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**

Permanent staff: 5

Postdoc: 3

Students:3

**Number of postdoctoral researchers:**

13 average on the last two years

**Number of graduate students resident at the facility:**

16 average on the last two years

**Number of non-resident graduate students with thesis work primarily done at the facility:**

More than 2 students per year

**Involvement of undergraduate students in research (approximate average number per year):**

7 per year, average on the last two years

**Special student programs:**

The Laboratory is involved in many training activities.

- The European Summer School on Experimental Nuclear Astrophysics (biennial), 30 students from all over the world;
- Master in “Monitoring on ionizing and non ionizing radiation and environmental risk”, first and second edition, 20 students;
- Course on Timing techniques in Nuclear Physics (every year) with an experiment at the tandem accelerator for PhD students, 10 students;
- Thesis proposals day for undergraduate students;
- Open doors for high school students, one week per year (about 3000 students per year).

**Future Plans:**

A growing activity in the accelerators field is planned in the coming years, in particular:

- In the frame of the European Spallation Source construction, the LNS is involved in the developing of the high intensity ion source and in the coordination of the LEBT.
- Regional funds have been assigned to the LNS for the construction of the Advanced Ion Source for HAdron therapy (AISHA).
- In the framework of the European Laser Infrastructure (ELI) the ELIMED experiment has to develop a beam line to use the proton beam laser driven to therapy treatment
- A construction of a test site cyclotron has been proposed with the support of a private company.

Moreover in the frame of the ESFRI KM3Net project a first block of the deepsea multidisciplinary laboratory, named KM3Net Italia is under development. The project foresees the realization of 32 Detection Unit to be deployed in Capo Passero site (3500 m below sea level, 80 km away from Sicily South East coast).
Scientific Mission and Research Programs:
The Frascati National Laboratory is the largest and the oldest laboratory of INFN whose peculiarity is the long and consolidated experience in the construction of accelerators. At present two facilities are in operation: the DAΦNE complex, an $e^+e^−$ factory, and the SPARC linear accelerator, a high brightness electron beam able to drive a self-amplified spontaneous free-electron laser (SASE-FEL). Other on site activities regard gravitational wave search with the NAUTILUS antenna, particle detector development, and research with synchrotron light.

Facilities:
DAΦNE: $e^+e^−$ storage ring, 1020 MeV c.m. energy, luminosity $5 \times 10^{32}$ cm$^{-2}$ s$^{-1}$, circumference 97.69 m, maximum current 5 A, number of bunches 1 – 120.
Beam Test Facility (BTF): $e^+/e^−$ beam line for detector calibration purposes, energy range 25-750 MeV, max repetition rate 50 Hz, intensity $1-10^{10}$ particle/pulse, pulse duration 1 – 10 ns.
DAΦNE-Light: four beamlines are operational using, in parasitic and dedicated mode, the intense photon emission of DAΦNE, ultraviolet and soft x-ray region (5-1000 eV).
SPARC_LAB: facility based on the combination of high brightness electron beams with high intensity ultra-short laser pulse.

Procedure to Apply for Beamtime:
Ask contact persons, or for BTF follow instructions at http://www.lnf.infn.it/acceleratori/btf/request.html
For DAΦNE-Light instructions are available at https://web2.infn.it/Dafne_Light/index.php/how-to-apply

Programme Advisory Committee (current membership):
LNF Scientific Committee has 1 in-house and 8 international members.
http://www.lnf.infn.it/committee/

Main Instrumentation for Particle Physics Experiments:
- KLOE superconducting spectrometer.

Main Fields of Particle Physics Research:
- Hadronic physics.

Main Instrumentation for Nuclear Physics Experiments:
- SIDDHARTA setup.

Main Fields of Nuclear Research:
- Low energy K^-nucleus interaction.
- Kaonic atoms study.

Other Fields of Research:
- Research with synchrotron light.
- Gravitational waves search.
- Theoretical physics.
- Accelerator physics.
- FEL research.
- Detector development.

Accommodation:
22 Guest rooms (28 Beds)
2 apartaments.

Transportation:
Railway station “Tor Vergata” at walking distance (line Rome–Cassino).
Frascati main railway station (3km from the laboratory).
INFN buses at fixed times connect the laboratory to the station “Anagnina” of Rome Metro line A.

SPARC-LAB

Special Student programs:
LNF hosts many initiatives for students, teachers and general public. The program of the forthcoming activities is available here:
http://www.lnf.infn.it/edu/
A post doctoral school is organized every year in May: “Spring School Bruno Touscheck”.

Future Plans:
In the next three years research at DAΦNE will continue with the KLOE2 experiment. The KLOE2 Collaboration will take data with a new vertex detector and new forward calorimeters with the goal of making precision measurements with 5-10 fb^{-1} integrated luminosity. The usage of the new subdetectors, is aimed at improving the performance of KLOE particularly for those "quantum interferometry" events that represent the true peculiarity of DAΦNE. The DAΦNE accelerator, besides the optimization of the machine parameters for KLOE2, aims at optimizing innovative collision schemes for other existing accelerators or for possible future projects.

A new experimental hall for high power Laser driven Plasma Wakefield particle Acceleration (LWFA) studies has been commissioned at LNF and is now in operation. With this new technique accelerating fields exceeding TV/m can be achieved and can be used to accelerate electron and proton beams with possible application to compact X-ray sources for medical diagnostics. By the end of 2013 the installation of the new beam lines dedicated to the experiments of plasma acceleration with
external injection, laser driven or Comb techniques, will be also completed. The main goal will be to demonstrate not only the high gradient achievable in these configurations but also the capability to maintain the high quality of the beam accelerated for future applications in Linear Colliders or Radiation Sources. In addition the realization (2015) of the first short wavelength FEL driven by plasma accelerated electron bunches, will be the innovative and excellent contribution of SPARC_LAB in the framework of the international competition.
Head of the facility:

Prof. Giovanni Fiorentini

Scientific Mission and Research Programs:

The Laboratori Nazionali di Legnaro (LNL) is a Nuclear Physics (NP) based, user-oriented Research Centre focused on Nuclear Structure and Nuclear Dynamics Studies, on Accelerator Technologies and on Applications of Nuclear Technologies. The impact of such activities on other research fields using ion beams, nuclear methods and techniques, such as Material, Earth and Life Sciences is getting every year stronger since the foundation of the Laboratories in 1968. Research activities have been continuously supported by intense R&D programmes covering proton and ion linacs, radiation and particle detector forefront technology.

The current main research programs for nuclear physics are:

- Structure of neutron–rich nuclei populated by binary reactions.
- Nuclear structure at high spins, proton rich nuclei and superdeformation.
- Fusion and grazing collisions around and below the Coulomb barrier.
- Fission and quasi–fission dynamics with heavy–ion beams.
- Nuclear structure at high excitation energy (giant resonances).
- Nuclear reactions induced by light ions and neutrons.

The main interdisciplinary research programs concern:

- Biophysics, medical physics, microdosimetry.
- Environmental physics.
- Solid state physics, material physics.
- Accelerator physics, superconductivity, RNB developments.

Within the European contracs (EC), the LNL is included, together with the Laboratori Nazionali del Sud of INFN, among the European large scale facilities providing access to their research infrastructures to research teams eligible for EC financial support.

A new radioactive ion beam facility (SPES) is presently under construction. Future programs for nuclear physics concern mainly the development of new instrumentation particularly suited for radioactive ion beams (RIB). Ongoing developments concern new generation gas and solid...
state detectors with related read-out electronics. Future programs for the accelerator technology are based on the upgrade in energy, beam intensity and ion species of the present accelerator complex, on the development of a radioactive ion beam facility, the SPES project, for the production and reacceleration of neutron rich beams based on ISOL technique and on the realization of the high intensity RFQ for the IFMIF project.

Photos of the facility and layout of the Tandem ALPI accelerator complex

Characterization of the Facility:
The present research basic facilities operating at LNL are:


PIAVE: ECR source + superconductive positive ion injector into ALPI.
7.0 MV CN Van de Graaff (V.d.G) accelerator (1961) mainly for Applied Physics and Interdisciplinary and Biomedical Physics (see in detail below)

2.5 MV AN2000 V. d. G. accelerator (1971) with 2.5 MeV Proton Microbeam (1994) for Applied physics and Interdisciplinary and Biomedical physics


Radiobiology Laboratory (1987) and Biomedical Laboratory for Interdisciplinary and Biomedical physics

AURIGA: Gravitational Wave Observatory (1995)

Table of maximum energy and current for some representative beams available at the Tandem-ALPI-PIAVE accelerator complex

<table>
<thead>
<tr>
<th>Beam species</th>
<th>Tandem *</th>
<th>Tandem+ALPI**</th>
<th>PIAVE+ALPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H</td>
<td>30</td>
<td>500</td>
<td>252</td>
</tr>
<tr>
<td>7Li</td>
<td>60</td>
<td>95</td>
<td>172 #</td>
</tr>
<tr>
<td>12C</td>
<td>90</td>
<td>450</td>
<td>305</td>
</tr>
<tr>
<td>22Ne</td>
<td>172</td>
<td>#</td>
<td>465</td>
</tr>
<tr>
<td>16O</td>
<td>105</td>
<td>370</td>
<td>391 #</td>
</tr>
<tr>
<td>32S</td>
<td>150</td>
<td>170</td>
<td>305</td>
</tr>
<tr>
<td>40Ar</td>
<td>165</td>
<td>13</td>
<td>518</td>
</tr>
<tr>
<td>40Ca</td>
<td>180</td>
<td>40</td>
<td>562</td>
</tr>
<tr>
<td>58Ni</td>
<td>180</td>
<td>40</td>
<td>549 #</td>
</tr>
<tr>
<td>84Kr</td>
<td>180</td>
<td>20</td>
<td>509</td>
</tr>
<tr>
<td>80Se</td>
<td>195</td>
<td>20</td>
<td>542</td>
</tr>
<tr>
<td>129Sn</td>
<td>195</td>
<td>20</td>
<td>654</td>
</tr>
<tr>
<td>132Xe</td>
<td>210</td>
<td>5</td>
<td>741 #</td>
</tr>
</tbody>
</table>

* estimated using 1 stripper foil (good for max. tandem transmission) and max ionization probability

** estimated for the state of charge of maximum probability obtained using a single foil stripper; using a double stripper the reachable energy substantially increases, but the available current reduces.

# beams presently available using PIAVE+ALPI only

SPES: the project is based on a high intensity proton cyclotron accelerating a 70 MeV proton beam onto a UCx target. Fission products are selectively ionized and, after mass analysis, reaccelerated using the present superconducting LINAC. The civil infrastructures for the SPES facility are now under construction. Main goal of SPES is the production of radioactive nuclear beams and of radioisotopes for medicine.

Facility’s major experimental instrumentation for nuclear physics (Tandem-ALPI-PIAVE accelerator):

PRISMA: large solid angle magnetic spectrometer for heavy ions with ion tracking capabilities, for binary reaction studies and possible upgrade for gas-filled operation.

GALILEO: array composed of a combination of 30 γ-ray Ge detectors with anti-Compton shields and 10 triple cluster Ge detectors realized with the capsules of the previous EUROBALL array. The system will complemented with a 4π Si ball for charged particles and a neutron detector (NEDA).

GARFIELD: high granularity 4π array for light particles and heavy fragments

EXOTIC: set-up for reaction mechanism studies with radioactive beams produced in-flight

PISOL one: time-of-flight spectrometer for transfer reactions and electrostatic deflector for evaporation residues.

RIPEN: neutron detector array for reaction studies

GAMPIE: set-up for g-factor measurements

TRAPRAD: magneto-optical trap (MOT) for atomic trapping of exotic nuclei

Facility’s major experimental instrumentation for interdisciplinary and biomedical physics (CN and Tandem accelerators):

- Radiobiology, to study the molecular and cellular biological effects induced by accelerated charged particles and neutrons in cultured cells
- Single-ion/single cell microbeam facility with an automated cell recognition, positioning and revisiting system
- Microdosimetry
- Trace element analysis of environmental, biomedical, geological and archeological samples using PIXE, PIGE and NRA techniques.
- Multi-elemental surface analysis using the Microbeam facility at AN2000 accelerator

Facility’s major experimental instrumentation for applied physics (AN2000 accelerator):

- Synthesis and characterization of advanced thin film materials and their treatment by chemical, thermal and ion beam methods
- Elemental analysis performed by means of the nuclear techniques - RBS, ERD, NRA, PIXE and PIGE
- Radiation damage and material modification studies using low energy light and heavy ions (1-14 MeV) as well as mono energetic neutrons (100 keV ÷ 8 MeV) and gamma rays

**Gravitational Wave Observatory**

**AURIGA** is an ultra-cryogenic detector for gravitational waves generated by impulsive sources in the Local Group of Galaxies. The 2.3-ton resonant bar cooled at 100 mK has a burst sensitivity of $4 \times 10^{-19}$ at 1kHz.

**User facility** Yes

**Program Advisory Committee/experiment proposals:**
All proposals are screened on the basis of scientific merit by the LNL Program Advisory Committee (PAC) for the Tandem-ALPI accelerator complex and by the User Selection Panel for Interdisciplinary Physics (USIP) for the smaller accelerators.

Program Advisory Committee/PAC (current membership): 0 in-house, 3 national, 4 international. User Selection Panel/USIP (current membership): 1 in-house, 4 national.

**Number of actual, active users of the facility in a given year:**
300 average number of individual users per year (including permanent staff).

**Percentage of users and percentage of facility use from inside the institution:**
10%, 10%

**Percentage of users and percentage of facility use from national users:**
>50% estimated percentage of external individual users per year

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
50%

**Fraction of international users outside of geographical region:**
5%

**Users group:**
Not applicable

**Number of:**
permanent staff: 128
temporary staff (incl. graduate students and postdoc researchers): 50 on average

**Number of theoretical staff:**
permanent: 0
postdoc: 0
students: 20

**Number of postdoc researcher:**
10 on average

**Number of graduate students resident at the facility:**
25 on average

**Number of non-resident graduate students with thesis work done at the facility:**
20 on average

**Involvement of undergr. students in research:**
20 on average

**Special student programs:**
- Summer student DOE: 1 students per year
- Stage for Secondary School and University students (yearly held from May to September): about 40 students
- Master on “Surface Treatments applied to Innovative Technologies for Industry”: 10 students
- Exhibition “Sperimentando”, held every year: interactive scientific exhibition to learn and enjoy oneself: 500 high school students.

**Future plans:**
SPES is a mid-term ISOL type facility for producing and accelerating radioactive ion beams of neutron rich species. This facility is part of the European Road Map prepared by NuPECC in view of the construction of the next generation ISOL facility (EURISOL).
OSLO CYCLOTRON LABORATORY (OCL)

Centre for Accelerator Based Research (SAFE)
Faculty of Mathematics and Natural Sciences, University of Oslo

Oslo, Norway

SAFE, University of Oslo
P.O. Box 1038 - Blindern
N0316 Oslo, Norway
http://www.safe.uio.no/
Telephone: +47 2285 5439
Facsimile: +47 2285 5441
E-mail: j.p.omtvedt@kjemi.uio.no

Establishment: Norwegian research council and University funds
Operation: University funds
Instrumentation: Norwegian research council and University funds

Head of the facility:
Prof. Jon Petter Omtvedt

Scientific Mission and Research Programs:
The Oslo Cyclotron Laboratory is the only particle accelerator in Norway dedicated to fundamental research within the fields of nuclear physics and chemistry. The local group focus on thermodynamic and electrodynamic studies of atomic nuclei. Research in nuclear chemistry is divided between two main research areas. The properties of super-heavy elements are studied by the SISAK group which use OCL for tests and development of equipment and systems to be used in heavy-ion experiments at other facilities. PET research, in particular development of new compounds suitable for PET studies, is the other focus area. OCL is part of the SAFE center (http://www.safe.uio.no) which supports and promotes basic and applied nuclear research in Norway.

Technical facilities:
Fig. 1: The Cactus detector array

Characterization of the facility:
Low-energy MC-35 cyclotron with light ion beams

Facility parameters:
Available beams from the MC-35 cyclotron:

<table>
<thead>
<tr>
<th>Particle type</th>
<th>Energy (MeV)</th>
<th>Beam intensity (uA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>2-35</td>
<td>100</td>
</tr>
<tr>
<td>Deuteron</td>
<td>4-18</td>
<td>100</td>
</tr>
<tr>
<td>$^3$He</td>
<td>6-47</td>
<td>50</td>
</tr>
<tr>
<td>$^4$He</td>
<td>8-35</td>
<td>50</td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:
The main experimental facility is:
- The CACTUS detector array with 28 NaI 5”x5” detectors and silicon particle telescopes.
- Target chamber with gas-jet (activity is transported with aerosols) transport to on-site chemistry lab.
- Type-A classified radiochemistry lab with hot-cells for e.g. PET-research is under construction.

Is the facility a user facility:
OCL is a part of the SAFE center, which welcome researchers from other institutions to use our facility, provided expenses are met and/or external funding can be found.

Program Advisory Committee/experiment proposals:
Proposals for experiments are evaluated by the “OCL Operation Group”, which handles scheduling of experiments.

Number of actual, active users of the facility in a given year:
OCL has an active user community of about 20 people, 60% in basic research, 10% in industrial application and 30% in medicine.

Percentage of users, and percentage of facility use that come from inside the institution:
Users from inside the institution 80% and facility users from inside the institution 50%

Percentage of users and percentage of facility use from national users:
National users 70% and facility used by national users 70%

Percentage of users and percentage of facility use from outside the country where your facility is located:
Foreign users 30% and facility used by foreign users 70%

Fraction of international users outside of geographical region:
10%

User Group:
No

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 11
b) 6

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
None

Number of postdoctoral researchers:
3

Number of graduate students resident at the facility:
13

Number of non-resident graduate students with thesis work primarily done at the facility:
4
Involvement of undergraduate students in research (approximate average number per year):
2

Special student programs:
Various student labs

Future Plans:
The lab has been totally refurbished in 2008, including a brand new and larger chemistry lab and new office work space for researchers during experiments. The cyclotron's power supplies (PSU) are very old and a major upgrade program was started in 2008 to replace them all. So far the two largest PSUs have been replaced and the plan is to replace all the smaller ones by the end of 2010. The upgrade project aims at bringing OCL up to a standard where it can be operated in a reliable manner for at least 10-15 years more.
HEAVY ION LABORATORY

University of Warsaw, Ochota Science Campus
Warsaw, Poland
PL 02 093 Warszawa, ul. Pasteura 5a
email: slcj@slcj.uw.edu.pl
Web address: www.slcj.uw.edu.pl

Heads of Institution and facility:
Krzysztof Rusek - Director
Ludwik Pieńkowski - Scientific Deputy Director
Jarosław Choński - Head of Accelerators
Jerzy Jastrzębski - PET Project Coordinator

Scientific Mission and Research Programs:
The Heavy Ion Laboratory is a “User Facility” with around 100 national and foreign users per year. The isochronous $K_{\text{max}}=160$ cyclotron delivers around 3000 h of heavy ion beams yearly with energies between 2 and 10 MeV/nucleon. The current research program comprises nuclear physics, atomic physics, material sciences, solid state physics, biology, particle detectors development and testing. For more details see Long Range Plan of Polish Nuclear Physics at www.slcj.uw.edu.pl/pnpn/en/52.html

Actually the Heavy Ion Laboratory is in its transformation phase to become the Warsaw University accelerator centre, operating two cyclotrons. In 2009 a second commercial proton – deuteron cyclotron ($E_p = 16.5$ MeV) will be installed in the Laboratory building for the production of – and research on the radiopharmaceuticals for the Positron Emission Tomography (PET). Production of long – lived radiopharmaceuticals for other medical and life– science applications is also foreseen.

Characterization of the facility:
Medium – energy (2 -10 MeV/nucleon) cyclotron with heavy ion beams;
Low – energy, high current proton – deuteron cyclotron.
Characterization of the facility:

a) Medium – energy (2 - 10 MeV/nucleon) cyclotron with heavy ion beams;
b) Low – energy, high current proton – deuteron cyclotron.

Table of facility parameters:

<table>
<thead>
<tr>
<th>Cyclotron</th>
<th>Ion</th>
<th>Energy [MeV]</th>
<th>Extracted current [pA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>K = 90 - 160</td>
<td>10B+2</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>11B+2</td>
<td>38 - 55</td>
<td>3 - 4</td>
</tr>
<tr>
<td></td>
<td>12C+2</td>
<td>22 - 50</td>
<td>2 - 20</td>
</tr>
<tr>
<td></td>
<td>14C+3</td>
<td>89.6 - 112</td>
<td>0.8 - 12</td>
</tr>
<tr>
<td></td>
<td>14N+2</td>
<td>28 - 50</td>
<td>13 - 143</td>
</tr>
<tr>
<td></td>
<td>15N+2</td>
<td>57 - 110</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>16O+2</td>
<td>32</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>16O+3</td>
<td>46 - 80</td>
<td>5.7 - 138</td>
</tr>
<tr>
<td></td>
<td>18O+4</td>
<td>90</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>19F+3</td>
<td>38 - 66</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>20Ne+3</td>
<td>50 - 65</td>
<td>11 - 35</td>
</tr>
<tr>
<td></td>
<td>20Ne+4</td>
<td>70 - 120</td>
<td>11 - 35</td>
</tr>
<tr>
<td></td>
<td>20Ne+5</td>
<td>140 - 190</td>
<td>24 - 40</td>
</tr>
<tr>
<td></td>
<td>22Ne+3</td>
<td>44</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>22Ne+4</td>
<td>132</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>24S+3</td>
<td>64 - 121.6</td>
<td>0.5 – 1.4</td>
</tr>
<tr>
<td></td>
<td>36Ar+6</td>
<td>80 - 132</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>40Ar+7</td>
<td>120 - 172</td>
<td>0.9 – 2.3</td>
</tr>
<tr>
<td></td>
<td>40Ar+8</td>
<td>195</td>
<td>0.9 – 2</td>
</tr>
</tbody>
</table>

\[
\begin{array}{|c|c|c|}
\hline
K=16.5 & ^1H^+ & 16.5 & > 75 \mu A \\
\hline
^2D^+ & 8.4 & > 60 \mu A \\
\hline
\end{array}
\]

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:

1. GDR multidetector system JANOSIK;
2. Gamma - ray, up to 30HPGe multidetector system EAGLE will be commissioned in 2009;
3. Two universal scattering chambers CUDAC and SYRENA;
4. Charged particle multidetector system ICARE;
5. Scandinavian type on-line mass separator IGISOL;
6. Irradiation chambers with target water cooling;
7. Low background lead shielded HPGe counters;
8. Radiochemistry and Quality Control equipment for the radiopharmaceuticals production;
For details see: www.slcj.uw.edu.pl/en/96.html

Nature of user facility:

Heavy Ion Laboratory (HIL) was founded jointly by the Ministry of Education and Sciences, Polish Academy of Sciences and Polish Atomic Energy Agency. In the founding agreement the above three authorities enacted HIL to become, from the very beginning a national “User Facility”.

Program Advisory Committee/ Experiment Proposals:

The K=160 cyclotron beam time is allocated by the Laboratory director on the recommendation of the Program Advisory Committee. The proposals are received twice a year (www.slcj.uw.edu.pl/pac) in a written form and publicly presented. In their ranking PAC considers the scientific value of the proposal, its expected international impact, its contribution to the teaching process and the previous achievements of the proposers.

Number of actual, active users of the facility in a given year:

About 100 users per year as indicated by the access record.

Percentage of users, and percentage of facility use:

About 10% of K=160 cyclotron users come from inside HIL. Less than 5% of the beam time is used by the HIL staff alone.
Percentage of users and percentage of facility use from national users:

About 80% of users come from Polish institutions.

Percentage of users and percentage of facility use from outside the country where your facility is located:

About 20% of users come from abroad.

Fraction of the international users outside of geographical region:

No users from outside Europe.

Users group:

The users group has an elected chair – person, who reports to the Laboratory Scientific Council. The facility users meet 3 times per year on a voluntary basis. No official record of people participating to the users group exists.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):

a) 50  
b) 13

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

No theoretical staff is employed at HIL.

Number of postdoctoral researchers:

10

Number of graduate students resident at the facility (>80% of their time):

5

Number of non-resident graduate students with thesis work primarily done at the facility:

15

Involvement of undergraduate students in research (approximate average number at a given time):

20 per year

Special student programs:

An undergraduate Student’s Workshop of one week duration is organized in March each year for about 20 participants coming from Physics Faculties of Polish universities. Students, supervised by the Laboratory staff are performing various nuclear physics experiments, including the cyclotron operation.

During Summer up to 7 students from various Physics Faculties take part in one month duration training, participating in experiments, conducted by the Laboratory staff.

Future Plans:

Heavy Ion Laboratory is conveniently placed in the heart of the Warsaw University, Polish Academy of Sciences and Academy of Medicine Scientific Campus Ochota. Shortly the intense proton and deuteron beams from a medical cyclotron, equipped with an external beam line will be also available. These beams will be used for the production of PET radioisotopes, subsequently transformed to radiopharmaceuticals using the commercially available chemistry and quality control modules. This 4 Million Euro project is currently financed by the Polish Ministry of Science and Higher Education, Ministry of Health, EC Structural Fund and International Atomic Energy Agency. The Polish Ministry of Health has also financed the PET scanner, located in the neighboring Medical University of Warsaw. Leading the Warsaw PET Consortium, the Laboratory foresees the development of a large interdisciplinary research program including medicine and life sciences, unique at least in this part of Europe.

For the K=160 cyclotron, a new ECR ion source allowing a substantial increase of the accelerated ion species and masses will be installed in 2009.

HIL is an open user facility, serving the needs of scientific community based mainly on evaluation of the merit of proposed programs only. Services provided: target laboratory, mechanical and electronic workshops, library, two conference rooms for 120 and 80 participants, respectively, 12 guest rooms with en-suite facilities and a common kitchen.
“HORIA HULUBEI” NATIONAL INSTITUTE FOR R&D IN PHYSICS AND
NUCLEAR ENGINEERING (IFIN-HH)

HVEC 9 MV Pelletron FN Tandem Accelerator
HVEE 3 MV Tandetron Accelerator
HVEE 1 MV Tandetron Accelerator
Department of Tandem Accelerators

Bucharest, Romania

30 Reactorului Str.
P.O. MG-6
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Telephone: +40-21-4042300
Facsimile: +40-21-4574440
http://tandem.nipne.ro
E-mail: secretar@nipne.ro

National Institute for Research and Development
Funding for construction: Romanian government
Funding for operation: Ministry of National Education, Romania
Instrumentation and Development: Grants from the Ministry of National Education and EU Programs

Nicolae Victor ZAMFIR, Director General of IFIN-HH

Heads of the facility:

Head of the Department of Tandem Accelerators: Dan Gabriel Ghiță
PAC Chair: Gheorghe Cata-Danil
Head of the Department of Nuclear Physics: Nicolae Marius Mărginean
Head of the Department of Applied Nuclear Physics: Florin Constantin

Scientific Mission and Research Programs:
The mission of the facility is to carry out competitive basic and applied scientific research using accelerated ion beams, and to provide training opportunities for undergraduate and PhD students, in collaboration with Romanian universities. The current research program encompasses nuclear structure physics, atomic physics, interdisciplinary research on material sciences, biology, medicine and environmental sciences, accelerator mass spectrometry (AMS) techniques and nuclear astrophysics. The facilities are open to Romanian and international users. The international Program Advisory Committee (PAC) that meets twice a year regulates the access to the facilities.

Technical facilities:
HVEC 9 MV Pelletron FN Tandem Accelerator
HVEE 3 MV Tandetron Accelerator
HVEE 1 MV Tandetron Accelerator

Characterization of the facilities:
9 MV FN Tandem Accelerator with pelletron charging system, operating at voltages up to 9 MV with light and heavy ions. Continuous beams and pulsed beams in the ms and ns range, 3 negative ion sources, one duoplasmatron with Li charge exchange channel and two SNICS II Cs sputter ion sources, carbon foil stripping system with 120 positions, and 7 experimental beamlines. The
general layout of the 9 MV tandem accelerator can be seen in Figure 1.

**Parameters of the 9 MV Tandem Accelerator**

With both ion sources we can accelerate a very wide variety of ion species, and some examples can be found below. The intensities for the beam currents can vary from tens of nA to microA on the target, depending on the ion specie.

Sputtering Ion Source: p, $^7$Li, $^9$Be, $^{10}$B, $^{11}$B, $^{12}$C, $^{14}$N, $^{16}$O, $^{19}$F, $^{24}$Mg, $^{28}$Si, $^{33}$S, $^{35}$Cl, $^{48}$Ti, $^{52}$Cr, $^{56}$Fe, $^{58}$Ni, $^{59}$Co, $^{63}$Cu, $^{79}$Br, $^{81}$Br, and $^{32}$S

Duoplasmatron Ion Source: d, $^4$He.

![Figure 1: General view of the FN Tandem accelerator, built by the High Voltage Engineering Corporation.](image1)

A neutron array detector, containing 81 cells, each 4 x 4 x 9.5 cm$^3$, of BC400 plastic scintillator, is available. Its efficiency for detecting a single

**Major experimental instrumentation and its capabilities:**

Department of Nuclear Physics has the following experimental facilities: 30 HPGe detectors with 55 % efficiency and anti-Compton shields, 12 clover detectors of 120 % efficiency with anti-Compton shields, 3 Ge planar detectors, and 12 LaBr$_3$:Ce fast scintillation detectors. ROSphere mixed detection array (Figure 2) consisting of up to 25 HPGe with anti-Compton shields and/or 12 LaBr$_3$:Ce fast scintillating detectors, is one permanent gamma spectroscopy setup.

A plunger device for measuring ps lifetime for excited nuclear states is also available.

Several neutron detectors and Si charged-particle detectors are also available. Analog electronics modules in NIM, CAMAC and VME standard and XIA digital electronics are used for signal processing and DAQ. A local area computer network with fast Internet access is used for data processing.

![Figure 2: ROSphere mixed detection array for γ-ray spectroscopy](image2)
neutron with E~13 MeV is ~30%. It can support counting rates up to 104 pulses /s.

3 Ge and 1 Si(Li) X-ray detectors as well as several scintillator, Si and microchannel plate charged particle detectors are presently available for atomic physics studies, using analog electronics modules in NIM and CAMAC standard for signal processing and data acquisition, ion-atom interaction studies involving X-ray and charged particle (electron, projectile or recoil ion) coincidence measurements.

A target chamber for characterization of materials by RBS, NRBS, NRA, ERDA and PIXE techniques was constructed and is presently installed on a beam line. Also, a second target chamber equipped with a ∆E-E telescope, initially devoted to charged particle spectroscopy, is currently used for ERDA measurements using heavy ion beams.

AMS facility. Low energy side: dedicated AMS injector deck with 40 sample MC-SNICS ion source, magnetic analyser, high vacuum and pre-acceleration stage of 100 kV; computer controlled. High-energy side: dedicated beam line with Wien Filter and AMS detection systems. For the detection of light nuclei a multi-array of Si-pin diodes system, Bragg detector and ∆E-E gas detector with TOF discrimination system for medium and heavy masses of particles are available.

3 MV Tandetron Accelerator

This accelerator is a valuable tool for elemental analysis, material characterization, ion implantation and nuclear astrophysics (Figure 3). The accelerator itself is a T-shape Crokroft-Walton type tandem accelerator equipped with two types of negative ion sources (a duoplasmatron ion source and a Cs sputter ion source) continued upstream with a 90° analyzing magnet. The accelerator has three beamlines and experimental endstations. The first measurements end station is dedicated for ion beam analysis (PIXE, PIGE, ERDA, RBS, etc.). The second end station is dedicated for ion implantation experiments, being equipped with beam swipping system, cooling system and heating system for the target, and multiple target holder. The third beamline is equipped with a multi purpose target chamber for various experiments (mainly dedicated to nuclear astrophysics).

The methods applied for analytical techniques are: Particle Induced X-ray Emission (PIXE), Particle Induced Gamma Ray Emission (PIGE), Elastic Recoil Detection Analysis (ERDA), and Rutherford Backscattering (RBS).

Applications of IBA techniques for elemental analysis and material characterization: geology and archaeometry, state of the art material science, ion channeling, study of ion-matter interaction, biomedical and environment. The implantation system offers the possibility to study material modifications (induced by accelerated ions).

Figure 3. The 3 MV Tandetron accelerator dedicated for ion beam analysis and ion implantation.

1 MV Tandetron Accelerator

The AMS system (Figure 4) is designed to measure very low isotopic ratios. The accelerator was commissioned to measure C, Be, Al and I isotopic ratios with the following experimental precision and background: (0.25 10^{-15}) for ^{14}C, (1.2 10^{-14}) for ^{10}Be, (0.8 10^{-14}) for ^{26}Al, and (1.7 10^{-14}) for ^{129}I. The accelerator uses a multiple cathode Cs sputter ion source with 50 samples/cathodes. A key component
of this facility is the 90° analyzing magnet equipped with a bouncer system. The technology of the bouncer system allows the alternative acceleration of two beams using a tunable high frequency bias voltage on its chamber. This feature enables the user to permanently monitor the isotope/element ratio with very low errors.

**Figure 4. 1 MV Tandetron accelerator for AMS.**

The accelerator system is a T-shape tandem accelerator with a Cockroft-Walton type charging system. The microscopic beam is measured with the help of a final particle detector (Bragg type - gas filled ionization chamber), placed after the final selection element, the 120° electrostatic analyzer (ESA). The possibility of performing analysis at a microscopic scale opens numerous applications in various domains such as: carbon dating of organic materials, material research, geology, determination of erosion rates, detection of existing nuclear pollution, forensic science and nuclear activity surveillance, diagnose of fusion experiments, astrophysics and oceanography, biomedical and pharmacological applications.

The sample preparation for all AMS analysis is performed in two specialized chemistry laboratories: a **General Chemistry Laboratory** to prepare the 10Be, 26Al and 129I samples, and a **14C Dating Laboratory** for the preparation of 14C samples. The chemistry laboratories include all essential equipment to perform the main chemical pre-treatment protocols that are currently used for all AMS analysis. After the chemical pre-treatment, the organic materials are transformed to graphite using a **fully automated graphitization unit (AGE III)** developed by Swiss Federal Institute of Technology, Zürich, Switzerland.

**Nature of facility:**
International User Facility

**Program Advisory Committee/experiment proposals:**

**Number of actual, active users of the facility in a given year:**
50 users per year.

**Percentage of users, and percentage of facility use that come from inside the institution:**
50%

**Percentage of users and percentage of facility use from national users:**
50%

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
50%

**Fraction of international users outside of geographical region:**
50%

**User Group:**
Beamtime requests can be sent by email at pac.bucharest@tandem.nipne.ro.

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**
- a) Total Staff working with the tandem accelerators: about 100
- b) Staff with doctoral degree: half of the staff has doctoral degrees

**Number of postdoctoral researchers:** 10

**Number of graduate students resident at the facility:** 2/year

**Number of non-resident graduate students with thesis work primarily done at the facility:** 5/year

**Involvement of undergraduate students in research (approximate average number per year):** 5 per year
Special student programs:

Romanian Summer Schools and Workshops in Nuclear Structure and Related Topics (http://www.nipne.ro) - yearly

Future Plans:

Technical developments:

Improvement of the control system of the 9 MV tandem accelerator, construction of a external beam system at the 3 MV Tandetron accelerator, construction of a sample holder for thin PIXE targets at the 3 MV Tandetron accelerator.
BUDKER INSTITUTE OF NUCLEAR PHYSICS / ROKK-1M

Novosibirsk, Russian Federation

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Novosibirsk 630090, Russia
Telephone: +7 (3832) 394026
Fascimilie: +7 (3833) 307163
E-mail: nikolenko@inp.nsk.su

Member of Russian Academy of Sciences (Siberian Branch)

Academy of Sciences, Russian Foundation of Fundamental Research, BINP budget.

Alexander N. Skrinsky

Head of the facility:
D.M. Nikolenko

Scientific Mission and Research Programs:
Investigation of the electromagnetic structure of the lightest nuclei in internal target experiments. The current program: Measurement of two-photon exchange contribution in elastic scattering of electrons/positrons on the proton, that is important for the interpretation experiments for proton electromagnetic form factors. Farther studies of the spin-dependent electromagnetic response of few-body nuclei with utilizing of pure polarized internal gas target.

Technical facilities:
Brief characterization of facility:
Electron/positron storage ring VEPP-3

Facility Parameters:
- Electron/positron beam energy from 350 MeV to 2 GeV
- Electron/positron beam current 150/50 mA
- Beam lifetime 30000 s
- Beam lifetime with polarized internal target 8000 s
- Beam cross section 0.3 x 0.7 mm
- Bunch repetition 4 MHz

Atomic Beam Source with strong superconducting magnets provides polarized deuterium atoms flux 8x10^{16} at/s for target with thickness 8x10^{13} at/cm^2. Non-magnetic particle detector covers the solid angle ~1 sr. It consists from tracking system, electromagnetic calorimeter 200 CsI and NaI crystals, proton and neutron scintillator counters.

Nature of user facility:
The facility can be used about 15% time of VEPP-3 (the other time is devoted to the high energy physics and synchrotron radiation experiments)

Program Advisory Committee/experiment proposals:
Scientific Council of BINP plays the role of Program Advisory Committee

Number of actual, active users of the facility in a given year:
An average over the last four years: 15

Percentage of users, and percentage of facility use that come from inside the institution:
60%

Percentage of users and percentage of facility use from national users:
79%

Percentage of users and percentage of facility use from outside the country where your facility is located:
21%

Fraction of international users outside of geographical region
North-America 14%
Europe 7%

User Group:
No

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 16 b) 4

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
permanent 3
postdoctoral 0
graduate students 0

Number of postdoctoral researchers:
4

Number of graduate students resident at the facility:
3

Number of non-resident graduate students with thesis work primarily done at the facility:
0

Involvement of undergraduate students in research (approximate average number per year):
2

Special student programs:
No

Future Plans:
The new Injection Complex of BINP will provide more intensive electron/positron beam in VEPP-3 for increasing of luminosity of internal target experiments. The new tagging system with photons energy from hundreds MeV to 1.5 GeV, which is under construction, will provide new possibilities for photonuclear experiments on the VEPP-3.
BUDKER INSTITUTE FOR NUCLEAR PHYSICS/VEPP-3 STORAGE RING/DEUTERON FACILITY

Novosibirsk, Russian Federation

Budker Institute for Nuclear Physics
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Novosibirsk 630090, Russia

Telephone: +7 383 3294760
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E-mail: nikolenko@inp.nsk.su

Member of Russian Academy of Sciences (Siberian Branch)

Academy of Sciences, Russian Foundation of Fundamental Research, BINP budget.

Alexander N. Skrinsky

Head of the facility:
Dmitry Nikolenko

Scientific Mission and Research Programs:
The main direction is study of the electromagnetic structure of the lightest nuclei in experiments with polarized internal targets. The current program: Measurement tensor analyzing power in the reactions of coherent and incoherent pions production on the deuteron. Measurement of two-photon exchange contribution in elastic scattering of electrons/positrons on the lightest nuclei. These experiment will use the advantage of VEPP-3 storage ring, where high enough luminosity in (e⁺p) and (e⁻p) scattering can be achieved. Future research program: measurement of tensor analyzing power in deuteron photodisintegration, pion and vector mesons photoproduction by tagged photons with energy up to 1500 MeV.
Technical facilities:

**Characterization of facility:**

Electron/positron storage ring VEPP-3

**Facility parameters:**

- Electron/positron beam energy from 350 MeV to 2 GeV
- Electron/positron beam current 150/50 mA
- Beam lifetime 30000 s
- Beam lifetime with polarized internal target 8000 s
- Beam cross section 0.3 x 0.7 mm
- Bunch repetition 4 MHz

**Brief and compact table with the facility’s major experimental instrumentation:**

Atomic Beam Source with strong superconducting magnets provides polarized deuterium atoms flux $8 \times 10^{16}$ at/s for target with thickness $8 \times 10^{13}$ at/cm$^2$. Non-magnetic particle detector covers the solid angle ~1 str. It consists from tracking system, electromagnetic calorimeter 200 CsI and NaI crystals, proton and neutron scintillator counters.
User facility:
The facility can be used 20% time of VEPP-3 (other 80% time is devoted to the high energy physics experiments)

Program Advisory Committee/Experiment Proposals:
Scientific Council of BINP plays the role of Program Advisory Committee

Number of actual, active users of the facility in a given year:
About 15 persons (plus several students).

Percentage of users, and percentage of facility use that come from inside the institution:
70% come from inside the institution.

Percentage of users and percentage of facility use from national users:
85%

Percentage of users and percentage of facility use from outside the Russia:
30%

Fraction of the international users from outside geographical region:
North-America and Europe: 2/1

User Group:
No.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) permanent staff - 7; b) temporary staff - 4

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
Permanent - 1; postdoctoral - 0; students -1;

Number of postdoctoral researchers:
1

Number of graduate students resident at the facility:
2

Number of non-resident graduate students with thesis work primarily done at the facility:
0

Involvement of undergraduate students in research:
2

Special student programs
No.

Future Plans:
New Injection Complex of BINP already may provides more intensive electron/positron beam in VEPP-3. Newly built the tagging system expands the opportunities for the performing of experiments.
INSTITUTE for HIGH ENERGY PHYSICS (IHEP)

Institute for High Energy Physics (IHEP) with:
Accelerator Complex U-70 comprising the proton (light-ion) synchrotron U-70 and its injector cascade of booster RCS U-1.5 and two complementary linacs — Alvarez DTL I-100 and RFQ DTL URAL-30

Geographic location:
Protvino, Russian Federation, Moscow Region

1, Nauki square, Protvino, Moscow Region, 142281, Russian Federation
http://www.ihep.ru
director@ihep.ru
tel: +7 (4967) 71-37-60
fax: +7 (4967) 74-49-37

(Legal) form/status of the institution/facility:
− State Research Center (functioning under Russian law)

Main sources of funding:
− a) construction — federal funding
− b) operation — federal funding, in part – and through commercial activities

Head of the institution:
Director Prof. Dr. Nikolai E. Tyurin

Heads of the facilities:
Experimental facilities - Prof. Dr. Alexander Zaitsev
Accelerators - Dr. Sergey Ivanov
Chief engineer – Boris Serebryakov

Scientific mission:
- Fundamental research in the field of high energy physics, getting new knowledge about the structure of matter.
- Maintaining and developing the national scientific potential and experimental base for research in high energy physics, developing key technologies in accelerator and beam physics and for elementary particle detectors; targeted applied research for high-tech industries.
- Educating new generation of researchers, facilitating higher grades of national education and professional training.

Technical facilities:
Synchrotron U-70 yielding 70 GeV protons and/or 34 GeV/u light ions (deuterons, carbon nuclei).
Layout:
Aerial view:

Facility characterization:

- **Proton (and light-ion) synchrotron**

Facility parameters:

<table>
<thead>
<tr>
<th></th>
<th><strong>U-1.5</strong></th>
<th><strong>U-70</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy, E</strong></td>
<td>0.030–1.32</td>
<td>1.32–69 GeV</td>
</tr>
<tr>
<td><strong>Orbit length, L</strong></td>
<td>99.16</td>
<td>1483.699 m</td>
</tr>
<tr>
<td><strong>Curvature radius, ρ</strong></td>
<td>5.73</td>
<td>194.125 m</td>
</tr>
<tr>
<td><strong>Magnet rigidity, Bp</strong></td>
<td>0.80–6.87</td>
<td>6.87–233 Tm</td>
</tr>
<tr>
<td><strong>Compaction factor, α</strong></td>
<td>0.07235</td>
<td>0.01120</td>
</tr>
<tr>
<td><strong>Intensity, N</strong></td>
<td>2–9×10¹¹</td>
<td>1.7×10¹¹ ppp</td>
</tr>
<tr>
<td><strong>Ramping time, t_R</strong></td>
<td>0.030</td>
<td>2.75 s</td>
</tr>
<tr>
<td><strong>Cycle period, T</strong></td>
<td>0.060</td>
<td>9.77 s</td>
</tr>
<tr>
<td><strong>RF harmonic, h</strong></td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td><strong>Radio frequency, f_RF</strong></td>
<td>0.75–2.75</td>
<td>5.52–6.06 MHz</td>
</tr>
<tr>
<td><strong>RF voltage, V_RF</strong></td>
<td>6–60</td>
<td>190–300 kV</td>
</tr>
<tr>
<td><strong>Lattice period</strong></td>
<td>MFDFM</td>
<td>FODO</td>
</tr>
<tr>
<td><strong>No. of periods</strong></td>
<td>12</td>
<td>60</td>
</tr>
<tr>
<td><strong>No. of super periods</strong></td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><strong>Betatron tune (H/V)</strong></td>
<td>3.85/3.80</td>
<td>9.9/9.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>URAL-30</strong></th>
<th><strong>I-100</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>RFQ DTL</td>
<td>Alvarez DTL</td>
</tr>
<tr>
<td><strong>Energy, E</strong></td>
<td>0.1–30</td>
<td>0.7–100 MeV</td>
</tr>
<tr>
<td><strong>Length, L</strong></td>
<td>25.3</td>
<td>79.4 m</td>
</tr>
</tbody>
</table>
Radio frequency, $f_{RF}$  
148.5      148.5 MHz

Pulsed current, $I$  
70      100 mA

Pulse length, $t_p$  
1–10      12–40 µs

Cycle period, $T$  
0.060      1–5 s

Sectioning  
5      3 tanks

Facility’s major experimental instrumentation and their research capabilities:

Facilities for research in fundamental physics:
- «OKA» (IHEP, INR, JINR), kaon decays and interactions;
- «VES» (IHEP), light meson spectroscopy;
- «SVD» (IHEP, JINR, SINP MSU), inclusive reactions;
- «MIS» (ITEP, IHEP), hadron spectroscopy;
- «FODS» (IHEP), hard hadron-nuclei interactions;
- «SPIN» (IHEP, JINR), hard hadron-nuclei interactions;
- «HYPERON» (IHEP), mesons in nuclear matter;
- «SPASCHARM» - under construction, (IHEP, JINR), spin physics.

Facilities for R&D and applications:
- «SIGMA» (IHEP), R&D for detectors development;
- «Channel 4A» (IHEP), R&D for beam optics with crystals;
- «Channel 6» (IHEP, JINR), R&D for detector development;
- «KMN-ATLAS» (IHEP, MPI,...), R&D for detector development (currently dedicated to the ATLAS upgrade at the LHC).

Program Advisory Committee adjudicating proposals for experiments:
Commission for Experimental Physics,
reporting to the IHEP Scientific Board

Number of actual, active users of the facility in a given year:
- 180 persons from IHEP (scientific and top engineering staff of experimental physics groups, this number nearly coincides with the number of persons with IHEP affiliation in publications made with the use of the IHEP facilities)
- 60 persons from other Russian laboratories (source: list of visitors/experiment participants)
- 10 users from abroad (source: list of visitors/experiment participants)

Percentage of users and percentage of facility use:
Estimation:
- Percentage of users that come from inside the institution: 70%
- Percentage of facility use that comes from inside the institution: 70%

Percentage of users and percentage of facility use from national users:
Estimation:
- Percentage of users that come from other national laboratories: 95%
- Percentage of facility use comprising national users: 95%

Percentage of users and percentage of facility use from outside the country:
Estimation:
- Percentage of users that come from outside the country: 5%
- Percentage of facility use that comes from outside the country: 5%

What fraction of the international users is from outside the geographical region of the facility:
**Estimation: 1%**

Formal users group with statues and an executive:
*Formal users groups exist for the IHEP staff. There are about 200 members of these groups. The situation for outside users is quite different. There are agreements (IHEP – user laboratory) for each activity at the IHEP facilities. The number of users is determined by the user institution or laboratory.*

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff:
- **Permanent staff:** 1900 ca
- **Temporary staff:** 100 ca

Number of theoretical staff employed at the facility:
- **Permanent** - 35
- **Postdoctoral** - 0 (not applicable)
- **Graduate students** - 3

Number of postdoctoral researchers employed by the facility:
- **Postdoctoral researchers employed/seconded at the facility:** 0

Number of graduate students resident at the facility (for more than 80% of their time):
- **20**

Number of non-resident graduate students with thesis work primarily done at the facility:
- **~5 per year (~250÷300 in total)**

Involvement of undergraduate students in research:
- **20**

Special student programs:
- **regular courses for students and graduate students (high energy physics – experiment, high energy physics – theory, detectors and experimental methods, accelerator and beam physics, data analysis etc.**

Plans that exist and their present status for future developments of the facility:
- **upgrade of power supply, extraction and other systems of the U-70 machine aimed to higher intensity and improvement of operation (approved, partially funded);**
- **upgrade of beam lines and detectors at the U-70 machine (approved, partially funded);**
- upgrades of the detectors for experiments with light ion beams (in preparation);
- construction of the Center of Ion Beam Therapy (partially approved);
- construction of the Facility for Intense Hadron Beams (LOI under consideration, this LOI can be found at: http://www.ihep.ru/ihep/news/omega_project.htm)

Facility outlay and photographs:

Fig. 1. Location of the U-70 complex.
Gray, blue and green – existing facilities
Red and pink- proposed Facility for Intense Hadron Beams.
Fig. 2 Proton Linac RFQ DTL URAL-30

Fig. 3 Booster RCS U-1.5

Fig. 4 The U-70 synchrotron
Fig. 5  Main experimental hall with beam-lines and detectors
INSTITUTE for NUCLEAR RESEARCH (INR)

Institute for Nuclear Research of the Russian Academy of Sciences (INR)

Geographic location:
Troitsk, Moscow Region, Russian Federation

60-letiya Oktyabrya prospekt 7a, Moscow, Russian Federation
inr@inr.ac.ru
tel. + 7 499 135 7760
fax + 7 499 135 2268

(Legal) form/status of the institution/facility:
Institute of the Russian Academy of Sciences

Main sources of funding:
Budget from Russian Federation

Head of the institution:
Academician Prof. Victor A. Matveev

Heads of the facility:
Prof. Leonid V. Kravchuk, Prof. Valery V. Kuzminov, Prof. Grigory V. Domogatsky

Scientific mission:

The main aims of INR are development of the experimental base for and fundamental research activities in the field of nuclear physics, elementary particle physics, cosmic-ray physics, and neutrino astrophysics. The Institute comprises the Moscow Meson Factory (MMF) including a high-current linear accelerator of protons and H ions, the experimental area, the neutron studies complex, and the Troitsk nu-mass installation (the city of Troitsk is near Moscow); the Baksan neutrino observatory (BNO, in the Caucasus); the Baikal deep underwater neutrino telescope detector (BUNT, in Lake Baikal). MMF is used for fundamental and applied investigations in nuclear physics, the study of materials, the production of radio-nuclides for medicine and industry, the development of proton therapy, and the production of radiopharmaceuticals for medical purposes; BNO and BUNT for the study of naturally occurring particle fluxes in a low background surrounding.

Technical facilities:

MMF linac:
BNO GGNT:

BUNT:
Facility characterization:

**MMF:** high current proton and neutron beam facility

**BNO and BUNT:** low background facility

Facility parameters:

**MMF linac**
- **Proton energy:** 200-500 MeV
- **Pulsed current:** 15 mA
- **Frequency:** 50 Hz
- **Beam species:** p, H

**MMF pulsed neutron source**
- **Neutron flux:** $10^{13} \text{n/sm}^2/\text{sec}$

**MMF Troitsk-NM**
- **Neutrino mass:** <2.05 eV

**BNO**
- **Low-background laboratories at a depth of 100, 600 and 4800 mwe**

**BUNT**
- **Submersion depth:** 1300 m
- **Detecting volume:** $10^6 \text{ m}^3$

Facility's major experimental instrumentation and their research capabilities:

**MMF**:
- **Pulsed neutron source providing neutron fluxes up to** $10^{13}$ **per sq. cm per sec within the interval from thermal energies to tens of MeV**
- **100t Pb Cube** – neutron spectrometer with the slowing-down time in lead
- **50m time-of-flight neutron spectrometer**
- **Facility of diffractometers for neutron studies**
- **Facility for gamma-ray material studies**
- **Facility for radio-nuclides production studies** ($^{82}\text{Sr}$, $^{68}\text{Ge}$, $^{109}\text{Cd}$, $^{22}\text{Na}$, etc)
- **Facility for studying proton and gamma therapy methods**
- **Troitsk-NM facility for neutrino mass measurements in the beta decay of tritium** (high-resolution beta-spectrometer on the basis of a large superconducting magnetic trap)

**BNO**:
- **Baksan Underground Scintillation Telescope (BUST)** with a volume of 300 m$^3$ at a depth of more than 300 m from the surface
- **Surface installation ANDYRCHI for detecting Extensive Air Showers. ANDYRCHI is located over BUST and covers about** $5 \times 10^4 \text{ m}^2$

A set of surface facilities KOVYOR comprising a Large Muon Detector, Scintillation Telescope and Neutron Monitor for studying the penetrating component of cosmic rays and Extensive Air Showers
Gallium-Germanium Detector for solar neutrinos located as deep in the mountain rock as 3600 m and having a target made of 60 tons of metallic gallium and a laboratory for germanium atoms extraction

Low-background laboratories at a depth of 100, 600 and 4800 mwe (3670 m from the mountain surface)

BUNT:
High energy neutrino detector with effective detection area more than 10^3 m^2 and controlled bulk of water of about 10^6 m^3

Is the facility considered to be a user facility?:
Yes

Program Advisory Committee adjudicating proposals for experiments?:
Yes

Number of actual, active users of the facility in a given year:
15 per year

Percentage of users and percentage of facility use:
80% (estimate)

Percentage of users and percentage of facility use from national users:
95%

Percentage of users and percentage of facility use from outside the country:
5%

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff:
- Permanent staff: 700

Number of theoretical staff employed at the facility: permanent; postdoctoral and graduate students:
- 70

Number of postdoctoral researchers employed by the facility:
- 7

Number of graduate students resident at the facility (for more than 80% of their time):
- 5

Involvement of undergraduate students in research:
- 2

Special student programs:
Every year the Baksan Youth School for experimental and theoretical physics, School for Students and Young Scientists "Basic Interactions and Cosmology"

Plans that exist and their present status for future developments at the facility:

**MMF:**
- Enlarge proton energy up to 1 GeV with superconductive resonators
- Development of diagnostic equipment
- Creating radio-nuclides radio-chemistry laboratory

**BNO:**
- New artificial neutrino source testing experiment

**BUNT:**
- Enlargement of controlled volume up to 1 km
Joint Institute for Nuclear Research (JINR)

Geographic location:
Dubna, Moscow region, Russian Federation

Joliot-Curie Street 6, Dubna, Moscow region, Russian Federation
E-mail: director@jinr.ru
Tel. + 7 496 21 65989
Fax + 7 496 21 65916

Legal form/status of the institution/facility:
- JINR- International Intergovernmental Scientific Research Organization

Main source of funding:
Budget from the JINR country-members

Head of the institution:
Academician Prof. Victor A. Matveev

Scientific mission:
The main fields of JINR's activity are theoretical and experimental studies in elementary particle physics, nuclear physics, and condensed matter physics.

Available at the Institute is a unique choice of experimental facilities. They include: the only in Europe and Asia superconducting accelerator of nuclei and heavy ions the Nuclotron, the U-400 and U-400M cyclotrons used for experiments on the synthesis of heavy and exotic nuclei, the unique IBR-2M reactor used for nuclear physics research with neutrons and condensed matter studies, and a proton accelerator - the phasotron that is used for particle therapy.

In the late 2008 a new basic facility - IREN-I - was successfully launched. The facility is to be used for the studies in nuclear physics with the time-of-flight method in the neutron energy range up to hundreds of keV. The Nuclotron-M project is also successfully progressing. It is to become the basis for the new superconducting collider NICA. The heavy ion complex DRIBs-II is actively under construction as well. JINR accounts for a half (about 40) of the total number of discoveries in nuclear physics, registered in the former Soviet Union. The decision of the International Committee of Pure and Applied Chemistry to award the name "Dubnium" to element 105 of the Periodic Table can be regarded as a sign of recognition of the outstanding achievements of JINR's staff of researchers in modern physics and chemistry.

Below follows information concerning three JINR Laboratories.

1. JINR Veksler-Baldin Laboratory of High Energy Physics (VBLHEP)

   Director: Prof. Vladimir D. Kekelidze

   The VBLHEP is carrying out experimental studies in elementary particle physics, nuclear physics, accelerator physics and in some fields of applied physics. The basic experimental facility of VBLHEP is the superconducting accelerator of protons, deuterons (and other light nuclei), medium and heavy ions – the Nuclotron. It is to become the basis for the new superconducting collider of nuclei up to Au – NICA.

   Technical facilities:
The Nuclotron (Fig.1, Fig. 2) is the basic facility of JINR for the generation of intense heavy ion and polarized nuclear beams.

Main scientific missions are
- Investigation of the mixed phase transition phenomena in strongly interacting nuclear matter at extremely high nuclear densities;
- Study of polarization phenomena in few nucleon systems and spin structure of quark matter, the nucleon, and light nuclei.
- Flavour physics (strangeness in nucleons and nuclei, lightest hypernuclei).

Future research program is related to the construction of the NICA facility, including two rings with intersecting beams.

Experiments are being carried out with internal beams at internal targets and with fixed targets at extracted beams in the dedicated experimental hall 205 (Fig.1). The slow extraction system provides spill durations up to 10 s with a duty factor up to 0.8.

Fig. 1. Technical layout of the Nuclotron and its instrumentation.
Facility characterization:

The future research program of VBLHEP is related to the construction of the NICA facility, including two rings with intersecting beams (Fig.3). It involves:
- development of the Nuclotron accelerator complex (construction of heavy ion linac and small booster synchrotron), as a base facility for studying relativistic nuclear collisions;
- development and construction of the heavy ion collider NICA, with multipurpose (NICA/MPD) and spin (NICA/SPD) detectors for collider experiments;
- upgrading of the external beam lines.

The collider will provide heavy ion collisions over the energy range $\sqrt{s_{NN}} \sim (4 – 11)$ GeV/u at an average luminosity level of $L = 1 \times 10^{27}$ cm$^{-2}$ s$^{-1}$, collisions of polarized deuteron beams (up to $\sqrt{s_{NN}} \sim 12$ GeV/u) and polarized proton beams (up to $\sqrt{s} \sim 25$ GeV) at a luminosity level of about $L \sim 1 \times 10^{31}$ cm$^{-2}$ s$^{-1}$.

Nuclotron will serve as the injector for the NICA rings. Preparation of the project is being monitored by an International Machine Advisory Committee.
Fig. 3. Technical layout of the future NICA facility: 1 - the existing accelerator building, 2 - fixed target experimental hall; 3 – collider ring; 4 and 5 - the MPD and SPD detector facilities respectively; 6 – high voltage electron cooling system.

Facility parameters:

Main parameters of the Nuclotron–superconducting heavy ion synchrotron.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference, m</td>
<td>251</td>
</tr>
<tr>
<td>Magnetic rigidity, Tm</td>
<td>45</td>
</tr>
<tr>
<td>Maximum field ramp, T/s</td>
<td>1</td>
</tr>
<tr>
<td>Beam species</td>
<td>From protons to Au, d↑</td>
</tr>
<tr>
<td>Maximum energy, GeV</td>
<td>12.6 (p), 6 GeV/u (Z/A=0.5), 4.5 (heavy ions)</td>
</tr>
<tr>
<td>Ion number per acceleration cycle</td>
<td>$10^{11}$ (p, d), $10^{10}$ (d↑), $10^9$ (heavy ions – will be increased up to $10^9$ after booster construction)</td>
</tr>
</tbody>
</table>
Facility's major experimental instrumentation and its research capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Problem and goals</th>
<th>Type of the instrument</th>
<th>Type of main detectors in use</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELTA-LNS</td>
<td>Study of 2- and 3-nucleon correlations in (d) break-up and elastic (dp) scattering</td>
<td>Non-magnetic spectrometer at internal beams</td>
<td>TOF system (PhMT), (\Delta E-E) with PhMTs, plastic scint. hodoscopes</td>
</tr>
<tr>
<td>Energy &amp; Transmutation</td>
<td>Study of neutronic characteristics of assemblies under (p) and (d) irradiation at 0.6-6 GeV kinetic energy. Study of neutron energy spectra and spatial distribution</td>
<td>Assemblies with Pb or U targets and blankets, Pb/C-moderators at extracted beams</td>
<td>Solid state detectors, detectors of delayed neutrons</td>
</tr>
<tr>
<td>FASA-3</td>
<td>Study of dynamics of nuclei thermal multi-fragmentation and (\text{liquid-fog}) phase transition.</td>
<td>Non-agentic spectrometer at extracted beams</td>
<td>Granulated (\Delta E-E) telescope (30 cells), 64 chan. multiplicity detector (CsI (Tl) scint.), (4\pi) acceptance</td>
</tr>
<tr>
<td>HyperNIS</td>
<td>Study of lightest hypernuclei ((^6\Lambda H, ^6\Lambda He, ^5\Lambda H) etc.) properties and production. Study of (\phi/\omega) production in (pp) and (dp) interactions close to threshold.</td>
<td>Non-focusing magnetic spectrometer at extracted beams</td>
<td>MWPCs, TOF system (RPCs), (\Delta E-E), plastic scint., scint. fiber hodoscope</td>
</tr>
<tr>
<td>Marusya</td>
<td>Study of sub-threshold and cumulative processes. Providing secondary beams for R&amp;D of detectors.</td>
<td>Focusing magnetic spectrometer at extracted beams</td>
<td>Plastic scint. hodoscopes, TOF system (PhMT), (\Delta E-E)</td>
</tr>
<tr>
<td>STRELA</td>
<td>Study of charge-exchange processes in (dp) interactions</td>
<td>Non-focusing magnetic spectrometer at extracted beams</td>
<td>Multiwire drift chambers, drift tubes, (\Delta E-E), TOF system (PhMT), plastic scint., Ch. with solid radiator</td>
</tr>
</tbody>
</table>

List of major new experimental instrumentation with fixed targets (planned):
User facility:

The Nuclotron is a user facility. It is reflected in the JINR Plan of Research; physicists from (more than) 26 countries have officially registered agreements and protocols of collaboration for experiments with Nuclotron beams.

Program Advisory Committee adjudicating proposals for experiments:

Any experiment suggested for Nuclotron beams is being considered by the JINR Program Advisory Committee for Particle Physics or by the Program Advisory Committee for Nuclear Physics. Approval by the corresponding PAC’s is being monitored by the VBLHEP Scientific and Technical Board.

Number of actual, active users of the facility in a given year:

In total: about 200 users (source: JINR Topical plan plus information from spokespersons of the collaborations working with the experimental installations listed above).

<table>
<thead>
<tr>
<th>Name (tentative)</th>
<th>Problem and goals</th>
<th>Type of beams; features</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM@N (Baryonic Matter at Nuclotron)</td>
<td>Study of dense baryonic matter and production of strange matter in heavy-ion collisions at beam energies between 2A and 6 A GeV</td>
<td>Extracted beams of nuclei up to Au; quasi-monochromatic neutrons (from d breakup) or protons. Large acceptance magnetic spectrometer with vertex detector (microstrip silicon trackers), TOF system (RPCs), multiwire drift chambers, multiplicity detector.</td>
</tr>
<tr>
<td>SPPT@N (Spectrometer with Polarized Proton Target at Nuclotron)</td>
<td>Study of polarization effects and spin-spin correlations in interactions of polarized deuterons, neutrons and protons with polarized protons (p) or deuterons (d), unpolarized p, d and nuclei.</td>
<td>Extracted polarized beams of d and quasi-monochromatic polarized neutrons or protons (from breakup of polarized d). Reconstructed polarized proton target with frozen spin. Magnetic spectrometer with polarimetric capability for secondaries with spin.</td>
</tr>
</tbody>
</table>
Percentage of users and percentage of facility use:

Percentage of users from inside the JINR: 60%; 40% of users are from other Institutions (both of member-countries and of countries being not JINR members). About 60% of the Nuclotron beam-time was used for experiments in the 2007-2011 years.

Percentage of users and percentage of facility use from national users:

JINR is the international institution; users from inside JINR have come from different countries. Therefore it is not clear what are “national users”. The beam time is being given to international collaborations as a whole without separation of their members with regard to nationality.

Percentage of users and percentage of facility use from outside the country:

About 40% of users are from outside the country where the facility is located (Russia). The beam time is being given to international collaborations as a whole without separation of their members according nationalities.

What fraction of the international users is from outside the geographical region of the facility:

North America: 6, Asia: 12, Australia: 2

Formal users group with statues and an executive:

No such formal users group exists yet

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff:

Permanent staff of the VBLHEP = 867
Including:
Scientific = 303
Specialists (engineers, technicians) = 293
Workers = 224
Management = 47
Temporary staff = 7

Number of theoretical staff employed at the facility:

VBLHEP is the experimental laboratory without special theory department, but any ongoing experimental study collaborates with theorists from the JINR Bogolyubov Laboratory for Theoretical Physics for theoretical support.
Number of postdoctoral researchers employed by the facility:
In the 2008-2011 period on average: 6 per year

Number of graduate students resident at the facility (for more than 80% of their time):
In the 2008-2011 period on average: 12 per year

Number of non-resident graduate students with thesis work primarily done at the facility:
No such statistics exists

Involvement of undergraduate students in research (approximate average number at a given time):
In the 2008-2011 period on average: 13 per year

Special student programs:
JINR has a special department – the University Center – which regularly organizes summer schools and courses/lectures for students. Apart from this, JINR organizes special permanently training schools for students and young scientists. VBLHEP participates in them.

Plans that exist and their present status for future developments of the facility:
The future research program at VBLHEP is related to the construction of NICA facility, including two rings with intersecting beams (Fig.3). It involves:
- development of the Nuclotron accelerator complex (construction of heavy ion linac and small booster synchrotron), as a base facility for studying relativistic nuclear collisions;
- development and construction of the heavy ion collider NICA, with multipurpose (NICA/MPD) and spin (NICA/SPD) detectors for collider experiments;
- upgrading of the extracted beam lines.
The collider will provide heavy ion collisions over the energy range $\sqrt{s_{NN}} \sim (4 – 11) \text{ GeV}$ at an average luminosity level of $L = 1 \cdot 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$, collisions of polarized deuteron beams (up to $\sqrt{s_{NN}} \sim 12 \text{ GeV}$) and polarized proton beams (up to $\sqrt{s} \sim 25 \text{ GeV}$) at a luminosity level of about $L \sim 1 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

Nuclotron will serve as the injector of the NICA rings. Preparation of the project is being monitored by the International Machine Advisory Committee.
For experiments at the NICA storage rings two big multipurpose detectors are in preparation:

<table>
<thead>
<tr>
<th>Name (tentative)</th>
<th>Problem and goals</th>
<th>Type of beams; features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPD: Multipurpose and multi-user detector</strong> for study of dense baryon matter study at colliding beams of heavy ions at NICA collider in the energy range $\sqrt{s_{NN}} = 4 - 11$ GeV/u</td>
<td>Study of dense baryon matter, phase transitions and search for mixed phase.</td>
<td>Heavy nuclei up to Au. Solenoidal detector with almost $4\pi$ acceptance and forward spectrometers</td>
</tr>
<tr>
<td><strong>SPD: Multipurpose and multi-user detector</strong> for study of nucleon spin structure at colliding beams of protons and deuterons at NICA collider in the energy range up to $\sqrt{s_{NN}} \sim 12$ GeV/u (deuterons) and to $\sqrt{s} \sim 25$ GeV (protons)</td>
<td>Study of polarization phenomena and structure of nucleon</td>
<td>Polarized deuteron and proton beams. Solenoidal detector with almost $4\pi$ acceptance and polarimeters</td>
</tr>
</tbody>
</table>

For experiments with fixed targets at extracted Nuclotron beams two multipurpose experimental instrumentations are planned to be constructed:

<table>
<thead>
<tr>
<th>Name (tentative)</th>
<th>Problem and goals</th>
<th>Type of beams; features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BM@N (Baryonic Matter at Nuclotron)</strong></td>
<td>Study of dense baryonic matter and production of strange matter in heavy-ion collisions at beam energies between 2A and 6 A GeV</td>
<td>Extracted beams of nuclei up to Au; quasi-monochromatic neutrons (from $d$ breakup) or protons. Large acceptance magnetic spectrometer with vertex detector (microstrip silicon trackers), TOF system (RPCs), multiwire drift chambers, multiplicity detector.</td>
</tr>
<tr>
<td><strong>SPPT@N (Spectrometer with Polarized Proton Target at Nuclotron)</strong></td>
<td>Study of polarization effects and spin-spin correlations in interactions of polarized deuterons, neutrons and protons with polarized protons ($p$) or deuterons ($d$), unpolarized $p$, $d$ and nuclei.</td>
<td>Extracted polarized beams of $d$ and quasi-monochromatic polarized neutrons or protons (from breakup of polarized $d$). Reconstructed polarized proton target with frozen spin. Magnetic spectrometer with polarimetric capability for secondaries with spin.</td>
</tr>
</tbody>
</table>
2. JINR Frank Laboratory of Neutron Physics (FLNP)

*The FLNP Director is Prof. Alexander V. Belushkin*

Technical facilities:

*The main experimental facility of JINR FLNP is the fast pulsed nuclear reactor IBR-2M which is used for nuclear physics research with neutrons and for condensed matter studies.*

![IBR-2M Reactor](image)

**IBR-2 spectrometers:**
- **Diffraction:** HRFD, DN-2, DN-12, DN-6, SKAT, EPSILON, FSD
- **Small-angle scattering:** YuMO
- **Reflectometry:** REMUR, REFLEX, GRAINS
- **Inelastic scattering:** DIN-2PI, NERA
- **Nuclear Physics:** ISOMER, KOLHIDA

**Facility characterization:**

*Pulsed fast neutron source*

**Facility parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IBR-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean power, MW</td>
<td>2</td>
</tr>
<tr>
<td>Fuel</td>
<td>PuO₂</td>
</tr>
<tr>
<td>Number of fuel elements</td>
<td>69</td>
</tr>
<tr>
<td>Maximal burn up, %</td>
<td>9</td>
</tr>
<tr>
<td>Repetition rate, Hz</td>
<td>5; 10</td>
</tr>
<tr>
<td>Pulse width for fast neutrons, µs</td>
<td>~200</td>
</tr>
<tr>
<td>Rotation speed, rpm</td>
<td>600; 300</td>
</tr>
<tr>
<td>main reflector (MMR)</td>
<td></td>
</tr>
<tr>
<td>auxiliary reflector (AMR)</td>
<td></td>
</tr>
<tr>
<td>MMR and AMR material</td>
<td>Nickel+steel</td>
</tr>
<tr>
<td>Moveable reflector service life, hours</td>
<td>55000</td>
</tr>
<tr>
<td>Background, %</td>
<td>7</td>
</tr>
<tr>
<td>Number of satellites at 5 Hz</td>
<td>1</td>
</tr>
<tr>
<td>Thermal neutron flux from the surface of moderator:</td>
<td></td>
</tr>
<tr>
<td>time average</td>
<td>$10^{13}$ n/cm²/s</td>
</tr>
<tr>
<td>burst maximum</td>
<td>$10^{16}$ n/cm²/s</td>
</tr>
</tbody>
</table>
Facility's major experimental instrumentation and their research capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Area and object of research</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN-2PI</td>
<td>Study of lattice dynamics of crystalline, amorphous materials and liquids</td>
</tr>
<tr>
<td>YUMO</td>
<td>Determination of structural characteristics (size and shape of particles, agglomerates, pores, fractals) of nanostructured materials and nanosystems, including polymers, lipid membranes, proteins, solvents, etc.</td>
</tr>
<tr>
<td>HRFD</td>
<td>Determination of structural parameters of crystalline materials (lattice parameters, atomic coordinates and thermal factors) with high precision</td>
</tr>
<tr>
<td>DN-2</td>
<td>Determination of structural parameters of crystalline materials and nanosystems (lipid membranes, etc), real-time studies of chemical and physical processes</td>
</tr>
<tr>
<td>EPSILON</td>
<td>In situ studies of macro- and microstresses in rocks</td>
</tr>
<tr>
<td>SKAT</td>
<td>Studies of texture of geological samples (rocks, minerals)</td>
</tr>
<tr>
<td>NERA</td>
<td>Study of lattice dynamics and structural parameters of molecular crystals, crystals with molecular ions, especially exhibiting polymorphism</td>
</tr>
<tr>
<td>REMUR</td>
<td>Determination of magnetization profile of layered magnetic nanostructures, studies of proximity effects in nanosystems</td>
</tr>
<tr>
<td>REFLEX-P</td>
<td>Determination of structural characteristics of thin films and layered nanostructures</td>
</tr>
<tr>
<td>FSD</td>
<td>Determination of residual stresses in bulk materials and products</td>
</tr>
<tr>
<td>DN-12</td>
<td>Determination of structural parameters of crystalline materials as a function of external pressures</td>
</tr>
<tr>
<td>DN-6 (under construction)</td>
<td>Determination of structural parameters of crystalline materials as a function of external pressures</td>
</tr>
<tr>
<td>GRAINS (under construction)</td>
<td>Studies of surface and interface phenomena in soft and liquid nanosystems (magnetic fluids, polymers, lipid membranes)</td>
</tr>
</tbody>
</table>

User facility:

The status as a user facility was approved by the JINR Directorate, but was suspended because of the reactor shutdown for upgrades in 2006. The upgraded IBR-2M reactor will restart user activities on a regular basis in 2012.

Program Advisory Committee adjudicating proposals for experiments:

There are three Commissions of Experts on: atomic and magnetic structure, lattice and molecular dynamics, on nano-systems and on soft matter.

Number of actual, active users of the facility in a given year: Approximately 100

Percentage of users and percentage of facility use: 25 %/25 %

Percentage of users and percentage of facility use from national users: JINR is an International Intergovernmental Scientific Research Organization therefore FLNP has employees from different
JINR Member States. So, if calling “national users” the users from Russia being not JINR employees, the percentage is 31.
The internal users (FLNP employees) comprise 25%.

Percentage of users and percentage of facility use from outside the country:
44 %

Fraction of the international users is from outside the geographical region of the facility:
From Asia – 5 %

Formal users group with statues and an executive:
Not at the present

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff:
a) 115
b) 22

Number of theoretical staff employed at the facility:
0

Number of postdoctoral researchers employed by the facility and by other institutions or laboratories:
2/0

Number of graduate students resident at the facility:
7

Number of non-resident graduate students with thesis work primarily done at the facility:
0

Involvement of undergraduate students in research (approximate average number at a given time):
3

Special student programs:
Regularly Schools and Special Lecture Series are being organized.

Plans that exist and their present status for future developments at the facility:
There is a development program for the spectrometer complex of the IBR-2 reactor. Its aims are to construct new spectrometers and to improve the technical parameters of the available spectrometers in order to extend the range of experimental applications for interdisciplinary scientific research.

3. JINR Flerov Laboratory for Nuclei Reactions (FLNR)
The FLNR Director is Prof. Sergey N. Dmitriev

Experimental facilities:
Low energy heavy ion isochronous cyclotron U400
Intermediate energy heavy ion isochronous cyclotron U400M
Heads of the facilities:
Accelerator Department: Boris N. Gikal
Chief Engineer: Igor V. Kalagin

Scientific mission:
The scientific activity of the Laboratory is concentrated on: synthesis of heavy and exotic nuclei in reactions induced by accelerated ions of stable and radioactive isotopes, study of their nuclear and chemical properties, investigation of mechanisms of nuclear reactions, study of the interaction of heavy ions with matter, accelerator physics, and applied physics investigations. The basic experimental facilities of the Laboratory are the isochronous heavy ion cyclotrons U400 and U400M.

Technical facilities:

Fig.1 General view of the isochronous cyclotron U-400

Fig.2 General view of the U-400M experimental hall
Facility parameters:

The isochronous U-400 cyclotron accelerates beams of ions from Li up to Xe and maximum energy up to 25 MeV/nucleon with an energy spread $\Delta E/E = 10^{-3}$. The accelerator has been equipped with an ECR ion source at 14 GHz - ECR4M for producing intense ion beams of rare isotopes like $^{48}$Ca, $^{50}$Ti, and $^{58}$Fe.

Table 1 Beams of the U-400 cyclotron

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy, MeV/n</th>
<th>Extracted beam intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^7$Li$^{1+}$</td>
<td>16.6</td>
<td>$6 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^6$Li$^{1+}$</td>
<td>12.6</td>
<td>$6 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{11}$B$^{2+}$</td>
<td>17.8</td>
<td>$4 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{12}$C$^{2+}$</td>
<td>16.6</td>
<td>$4 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{13}$C$^{2+}$</td>
<td>14.4</td>
<td>$3 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{14}$N$^{2+}$</td>
<td>9.4</td>
<td>$3 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{14}$N$^{3+}$</td>
<td>20.3</td>
<td>$3 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{18}$O$^{3+}$</td>
<td>19.3</td>
<td>$2 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{20}$Ne$^{4+}$</td>
<td>20.9</td>
<td>$2 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{22}$Ne$^{4+}$</td>
<td>17.8</td>
<td>$2 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{36}$S$^{5+}$</td>
<td>15</td>
<td>$9 \times 10^{12}$ pps</td>
</tr>
<tr>
<td>$^{40}$Ar$^{8+}$</td>
<td>19.9</td>
<td>$1 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{48}$Ca$^{5+}$</td>
<td>5.3</td>
<td>$7 \times 10^{12}$ pps</td>
</tr>
<tr>
<td>$^{48}$Ca$^{9+}$</td>
<td>19</td>
<td>$3 \times 10^{12}$ pps</td>
</tr>
<tr>
<td>$^{86}$Kr$^{9+}$</td>
<td>5.1</td>
<td>$2 \times 10^{12}$ pps</td>
</tr>
<tr>
<td>$^{136}$Xe$^{14+}$</td>
<td>4.4</td>
<td>$3 \times 10^{10}$ pps</td>
</tr>
</tbody>
</table>

The U-400M cyclotron provides for ion beams of light elements from D to Ca with energies up to 50 MeV/nucleon (maximum energy is 100 MeV/nucleon). The accelerator has been equipped with an ECR ion source at 14 GHz – DECRIS-14. The U400M as stand-alone delivers ion beams to experimental setups and as a driving accelerator for producing light radioactive nuclei, in particular, in tandem operation mode with the U400.

Table 2 Beams of the U-400M cyclotron

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy, MeV/n</th>
<th>Extracted beam intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^7$Li$^{2+}$</td>
<td>35</td>
<td>$6 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{11}$B$^{3+}$</td>
<td>32</td>
<td>$4 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{12}$C$^{4+}$</td>
<td>47</td>
<td>$4 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{14}$N$^{4+}$</td>
<td>35</td>
<td>$3 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{14}$N$^{5+}$</td>
<td>54</td>
<td>$1.5 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{18}$O$^{5+}$</td>
<td>33</td>
<td>$2.5 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{22}$Ne$^{6+}$</td>
<td>32</td>
<td>$1 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{22}$Ne$^{7+}$</td>
<td>43</td>
<td>$1 \times 10^{13}$ pps</td>
</tr>
<tr>
<td>$^{36}$S$^{10+}$</td>
<td>33</td>
<td>$6 \times 10^{11}$ pps</td>
</tr>
<tr>
<td>$^{40}$Ar$^{12+}$</td>
<td>40</td>
<td>$7 \times 10^{11}$ pps</td>
</tr>
<tr>
<td>$^{48}$Ca$^{10+}$</td>
<td>20</td>
<td>$5 \times 10^{11}$ pps</td>
</tr>
</tbody>
</table>
Facility's major experimental instrumentation and their research capabilities:

**U400:**
1. Dubna Gas-Filled Recoil Separator “DGFRS”
   The Dubna gas-filled recoil separator was put into operation in 1989. Since then many improvements were introduced. Special emphasis was laid on the possibility of applying very intense heavy-ion beams delivered by the JINR U400 cyclotron to radioactive and exotic target species like $^{242,244}$Pu, $^{243}$Am, $^{248}$Cm, $^{249}$Cf. The separator has DQQ design and is filled with dilute hydrogen gas. The separated evaporation residues pass through a time-of-flight measurement system and are implanted in a position-sensitive detector (PSD) array.

2. Electrostatic separator VASSILISSA-II
   The electrostatic separator VASSILISSA is used for exploring fusion reactions. In the process of upgrading the magnetic $37^\circ$-dipole was installed downstream of the second quadrupole triplet of the separator for mass identification of evaporation residues. Mass determination is an additional method for the identification of new isotopes when traditional methods are insufficient. In experiments with "VASSILISSA II", the mass resolution $\Delta m/m$ in test reactions better than 1% was achieved, for single events the mass resolution is better than 2%.

3. Spectrometer of fission fragments “CORSET”
   The time-of-flight spectrometer CORSET is designed for the detection of fission fragments in correlation with the emission of pre- and post-scission neutrons and $\gamma$-quanta. The upgrade was introduced in view of using the CORSET set-up in tandem with the multi-detector neutron spectrometer DEMON. An important aspect is the use of the “neutron clock” method for the study of time characteristics of the process of formation and decay of super-heavy nuclei formed in reactions with heavy ions. CORSET provides a precise time ($\sim 150$ ps $\rightarrow \Delta A/A \sim 1.5\%$ for charged reaction products) and position resolution. The geometry efficiency of the setup is $\sim 3-5\%$.

4. MSP-144
   "MSP-144" magnetic analyzer is able to separate the elastically scattered ion beam in order to accumulate reaction products and to distribute them in compliance with $A$-mass dispersion and $q$-charge with appropriate resolution ($\Delta p/p$). The possibility to widely vary the reaction product detection angle is one of the advantages of this analyzer.

**U400M:**
1. Wide aperture fragment-separator “COMBAS”
   The kinematics separator COMBAS, having large solid angle and high momentum acceptance, was specially designed to collect efficiently short-lived nuclei close to zero degrees which are produced in intermediate energy large mass transfer reactions. It can be used efficiently both in the mode of a high resolving spectrometer to study reaction mechanisms and in the mode of an in-flight separator in experiments on the synthesis and study of the properties of nuclei near the drip-lines.

2. Fragment-separator “ACCULINNA”
   The set-up of ACCULINNA is intended for cleaning and transportation of secondary beams of light radioactive nuclei. The separator involves an achromatic ion-optical system (two 35 degree dipole magnets, eight quadrupole and two sextupole magnetic lenses intended for separation of secondary exotic beams of magnetic rigidity up to 3.8 T·m emerging from the production target close to zero degrees with respect to the incident beam direction.

3. Mass-spectrometer “MASHA”
   This separator is destined for the separation and mass analysis of super-heavy element ions with masses $A=288\pm12$, energy $E=40$ keV and charge state $Q=+1$. The separator mass resolution exceeds 1000. This separator is designed for an ion beam with $35\pi$ mm-mrad emittance (in horizontal and vertical planes) emergent from the ECR source with a circular discharge outlet of 5 mm diameter.
User facility:

The cyclotrons are not considered user facilities. Nevertheless performing the experiments in collaboration with groups from other laboratories is customary practice.

Program Advisory Committee or the equivalent, adjudicating proposals for experiments:

The scientific program for the FLNR facilities has to be approved by the nuclear physics PAC.

Number of actual, active users of the facility in a given year:

An average number of scientific groups (or “users”) exploiting given facility is:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Number of Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>11</td>
</tr>
<tr>
<td>U400M</td>
<td>11</td>
</tr>
</tbody>
</table>

Percentage of users and percentage of facility use:

Percentage of users from inside the institution:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>45%</td>
</tr>
<tr>
<td>U400M</td>
<td>45%</td>
</tr>
</tbody>
</table>

Percentage of facility use by home users:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>40%</td>
</tr>
<tr>
<td>U400M</td>
<td>65%</td>
</tr>
</tbody>
</table>

Percentage of users and percentage of facility use from national users:

Percentage of national users:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>0%</td>
</tr>
<tr>
<td>U400M</td>
<td>18%</td>
</tr>
</tbody>
</table>

Percentage of facility use by national users:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>0%</td>
</tr>
<tr>
<td>U400M</td>
<td>25%</td>
</tr>
</tbody>
</table>

Percentage of users and percentage of facility use from outside the country:

Percentage of users from outside the country:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>55%</td>
</tr>
<tr>
<td>U400M</td>
<td>37%</td>
</tr>
</tbody>
</table>

Percentage of facility use by foreign users:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>60%</td>
</tr>
<tr>
<td>U400M</td>
<td>10%</td>
</tr>
</tbody>
</table>

Fraction of the international users is from outside the geographical region of the facility:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>36%</td>
</tr>
<tr>
<td>U400M</td>
<td>18%</td>
</tr>
</tbody>
</table>

Formal users group with statues and an executive:

A formal user group does not exist

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Permanent Staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>U400</td>
<td>scientific staff – 38</td>
</tr>
<tr>
<td></td>
<td>technical staff – 7</td>
</tr>
<tr>
<td></td>
<td>administrative staff – 1</td>
</tr>
<tr>
<td>U400M</td>
<td>scientific staff – 33</td>
</tr>
<tr>
<td></td>
<td>technical staff – 7</td>
</tr>
<tr>
<td></td>
<td>administrative staff – 1</td>
</tr>
</tbody>
</table>
Number of temporary staff
U400:  15
U400M:  29

Number of theoretical staff employed at the facility:
Permanent staff
U400:  6
U400M:  2
Graduate students
U400:  1
U400M:  1

Number of postdoctoral researchers employed by the facility:
U400:  3
U400M:  1

Number of graduate students resident at the facility (for more than 80% of their time):
U400:  3
U400M:  0

Number of non-resident graduate students with thesis work primarily done at the facility:
U400:  0
U400M:  3

Involvement of undergraduate students in research (approximate average number at a given time):
U400:  26
U400M:  18

Special student programs:
Scientific training for students at FLNR includes annual lecture series and work at the facilities (organized for students from universities of Russia, Eastern Europe, and South Africa)

Plans that exist and their present status for future developments at the facility:
A 7-year plan for JINR asks for a large extension of the experimental base of the laboratory aimed at the study of properties of the transuranium elements as well as light exotic nuclei, the investigation of reaction mechanisms induced by heavy ions, the synthesis of super-heavy elements and various applied physics projects. The plan includes construction of a new experimental hall with an area of about 2500 m², a new high current accelerator for heavy ions – the cyclotron DC280, a new radiochemical laboratory, and a number of facilities that have to provide an increase in experiment efficiencies. In particular, a new gas-filled separator and fragment separator are planned to be constructed in the immediate future. A number of other projects are proposed for consideration by the Program Advisory Committee.

Note added by the Secretary of IUPAP WG.9:

See also:  http://accelconf.web.cern.ch/AccelConf/PAC10/talks/tuzra02_talk.pdf
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Russia

Telephone: 7-813-7146047
Facsimile: 7-813-71-3-1347
E-mail: pnpi@lnpi.spb.su

Institute belongs to Russian Academy of Science (RAS)
Main source of funding: Budget of RAS of Science and Education Russian Federation

V. A. Nazarenko

Heads of the facilities:
High Energy Physics - RAS, Alexey Vorobyev
Theoretical Division - Lev N. Lipatov
Neutron Research Dept – Prof. Valery Fedorov

Scientific Mission and Research Programs:

Main research program of HEPD.
- Elementary particle physics (experiments on LHC, Tevatron-USA, Desy-Germany),
- Nuclear Physics (experiments at PNPI, JINR-Dubna, ISOLDE-CERN, GSI- Germany, Cosi-Germany, PSI-Switzerland, K-130-Jyvaskyla, Finland)
- Solid state physics (MSR-experiments at PNPI and PSI); Radiation physics and Proton therapy at PNPI synchrocyclotron.

All above shown experiments cover as current as well future ones.

Technical facilities:
1. Synchrocyclotron on proton energy of 1000 MeV
   1. Acting atomic reactor
   2. Building atomic reactor ”PIK”

Characterization of the facility:
The biggest synchrocyclotron in the world with proton energy of 1000 MeV.
Table of facility parameters:

- Technical parameters of HEPD facility-synchrocyclotron:
  - Energy of extracted protons-1000 MeV,
  - Intensity of inner beam-3 mkA,
  - Intensity of extracted beam-1 mkA
  - Energy spread of beam 0.1%.
- Intensities and energies of second beams:
  - Pions $+/(3-10)E5$ for $P=450$ MeV/c,
  - Muons $+/(9-30)E4$ for $P=170$ MeV/c,
  - Neutrons of $E=0.01$ eV-200 MeV
  - Total intensity-$3E14$/sec
  - Total area-20000 m²

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>NAME OF SETUP AND DIRECTION OF ACTIVITY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mass-separator IRIS for the study of short-lived nuclei far from the beta stability region (analogue of ISOLDE, CERN).</td>
<td>Measurements of electromagnetic moments and charge radii of radioactive nuclei by resonancelaser spectroscopy.</td>
</tr>
<tr>
<td>2 Time-of flight neutron spectrometer (GNEIS).</td>
<td>Energy of neutrons $E=0.01$ Eev-200 MeV. Full intensity is $3E14$/sec. 3·10¹⁴ n/sec.</td>
</tr>
<tr>
<td>3 MSR facility on muon beam. Investigations on solid state physics using muon spin rotation method</td>
<td></td>
</tr>
<tr>
<td>4 Two shoulder magnetic spectrometers system (MAP) for measurement of incident and recoil protons with energy 100-1000 MeV.</td>
<td>Study of nuclear matter density distributions by the method of proton elastic scattering, investigation of nuclear structure by quasielastic proton scattering</td>
</tr>
<tr>
<td>5 Electromagnetic calorimeter on the basis of CeI crystals.</td>
<td>Investigation of η-meson formation.</td>
</tr>
<tr>
<td>6 Experimental variable proton energy facility in the range 200-800 MeV.</td>
<td>Intensity of 200 MeV proton beam is $3E8$ proton/sec. 3·10⁵ sec⁻¹.</td>
</tr>
<tr>
<td>7 Complex of stereotaxic radiation therapy on 1000 MeV proton beam.</td>
<td>Measurements of fission cross sections for a number of heavy targets as a function of proton energy.</td>
</tr>
<tr>
<td></td>
<td>Treatment of different diseases of head brain. Since 1975 till 2005 1280 patients were treated by this method.</td>
</tr>
</tbody>
</table>

Nature of user facility:

PNPI synchrocyclotron is considered as a user facility.

Foreign members of it are:
- ISOLDE Collaboration, GANIL (France),
- (Japan), INFN (Italy), Argonne Lab. (USA), GSI (Germany), LHC (CMS, ATLAS, ALICE,
Program Advisory Committee/experiment proposals:

Our facility has a Program Advisory Committee with the goal of adjudicating experiment proposals.

Percentage of users and percentage of facility user from national users:

The estimated number of national users is 15% of the total number.

Percentage of users and percentage of facility use from outside the country where your facility is located:

We estimate a number of users outside the country as 10-15%.

Fraction of the international users outside of geographical region:

The main fraction of international users is from Europe and Japan (Asia).

This number is equal to above shown number 10-15%.

The formal user group is organized now in HEPD facility.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):

Permanent scientific stuff of HEPD consists of 200 physicists and engineers.

Number of graduate students resident at the facility:

A number of graduated students in HEPD is in average 12.
MAX IV LABORATORY

Lund, Sweden

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Facsimile: +46 46 222 4710
E-mail: maxlab@maxlab.lu.se
Web address: www.maxlab.lu.se

National facility

Construction: Government funds (The Swedish Research Council and the Lund University) and private foundations such as the Knut and Alice Wallenberg Foundation,
Operation Government funds (The Swedish Research Council and the Lund University).

Head of the facility:
Prof. Christoph Quitmann

Scientific Mission and Research Programs:
The MAX IV Laboratory is a multi-program national facility consisting of the present MAX-lab, in operation since more than 25 years, and a new synchrotron radiation facility, MAX IV, presently under construction. At the present MAX-lab research is done in three disciplines: Accelerator physics research; Synchrotron radiation based research (Physics, Chemistry, Life sciences, applied subjects), and Nuclear physics research. A guide to the scientific research can be found at www.maxlab.lu.se. The current research in Nuclear physics is based on the access to monochromatic photons in the energy range 15 to 180 MeV. The research program includes studies of Compton scattering, pion production, knockout reactions and total photo absorption cross sections in light nuclei. The new synchrotron light facility, MAX IV, consists of a 3 GeV linear accelerator serving two low emittance electron storage rings operated at 3 GeV and 1.5 GeV, respectively. A free electron laser facility is also planned and the inclusion of backscattering of laser light from the 3 GeV ring is investigated.

Technical facilities at the present MAX-lab:
**Characterization of the facility:**

The nuclear physics part of the laboratory consists of a pulsed linear accelerator with a nominal maximum energy 250 MeV and a pulse stretcher ring, MAX I. The continuous electron beam is used to produce a bremsstrahlung beam with high duty factor. A monochromatic photon beam is achieved via the tagging method.

**Facility parameters:**

<table>
<thead>
<tr>
<th>Facility parameters</th>
<th>In 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum electron energy</td>
<td>200 MeV</td>
</tr>
<tr>
<td>Duty factor</td>
<td>0,8</td>
</tr>
<tr>
<td>Operating current</td>
<td>30 nA</td>
</tr>
<tr>
<td>Tagged photon energy range</td>
<td>10 – 180 MeV</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>&lt; 150 keV</td>
</tr>
<tr>
<td>Tagged photon intensity</td>
<td>0,5 MHz per MeV</td>
</tr>
</tbody>
</table>

**Brief and compact table with the facility’s major experimental instrumentation and its capabilities:**

Major experimental instrumentation

- 2 tagging spectrometers
- 4 25 cm x 25 cm NaI(Tl) spectrometers
- 3 ≈ 50 cm x 50 cm NaI(Tl) spectrometers (BUNI, CATS, DIANA)
- SSD/SSD/CsI telescope
- Si-Si and Si-HPGe telescopes
- 4 large Si-Si-HPGe telescopes (Ge6)
- 4 dE-E plastic scintillator telescopes
- 3 range telescopes
- Liquid scintillation neutron detectors (NORDBALL)
- Time of flight neutron detector wall 6 m²
- Targets for liquid deuterium and helium
- A goniometer for coherent bremsstrahlung production
User facility:
MAX-lab is an official user facility.

Program Advisory Committee/Experiment Proposals:
MAX-lab has a Program Advisory Committee that allocates beamtime to projects based on the scientific merits of these projects. MAX-lab also has a Scientific Advisory Committee for all activities at the laboratory.

Number of actual, active users of the facility in a given year:
The total number of active users per year at all beamlines at MAX-lab is about 940 and the majority of these are using the facility for synchrotron radiation based research. The number of nuclear physics users is about 50. These numbers refer to the number of individuals annually using the facility and is obtained from the registration in connection with experiments at the facility.

Percentage of users that come from inside the institution:
Less than 5% of the nuclear physics users come from inside MAX-lab. The same number is valid for all users of the facility.

Percentage of users and percentage of facility use from national users:
About 10% of the nuclear physics users come from Swedish institutions and about 15% of the beamtime is used by Swedish nuclear physics users. The corresponding numbers for all users of the facility are 44% and 42%, respectively.

Percentage of users and percentage of facility use from outside the country where the facility is located:
About 90% of the nuclear physics users come from outside Sweden. About 85% of the facility use for nuclear physics is for non-Swedish users. The corresponding numbers for all users of the facility are 56% and 58%, respectively.

Fraction of the international users from outside Europe:
About 90% of the nuclear physics users come from outside the Nordic countries and about 60% of the nuclear physics users come from outside Europe. The corresponding numbers for all users of the facility are 27% and 5%, respectively.

Users group:
The Association of Nuclear Physics Users at MAX-lab has 97 members coming from 42 different institutions.

Number of permanent staff and temporary staff:
The total number of permanent staff at the facility is about 140 in 2013.

Number of theoretical staff employed at the facility:
At present (2013) there are no theoretical staff employed at the laboratory.

**Number of postdoctoral researchers:**
There are 15 postdoctoral researches employed by the facility in 2013.

**Number of graduate students resident at the facility:**
There are 10 graduate students resident at the facility in 2013.

**Number of non-resident graduate students with thesis work primarily done at the facility:**
The number of non-resident graduate students with thesis work primarily done at the facility is estimated to be about 50.

**Special students programs:**
For the synchrotron radiation oriented students there are Nordic summer schools organized every second year. There is a course at the undergraduate level which is called “The Frontiers of Science”, which extends over a year (7.5 ECT points). The students follow the work of a specific research group at MAX-lab during a year and meet group members about once per week. The students also participate actively in a seminar series with seminars every second week with speakers mainly from the Science Faculty.
Scientific Mission and Research Programs:
The Large Hadron Collider (LHC) currently under construction at CERN will come into operation in 2007. Besides proton-proton collisions, aimed at exploring particle physics at the TeV scale, both proton-nucleus and nucleus-nucleus collisions are foreseen as a significant part of the experimental program. With heavy ions at a center-of-mass energy of 5.5 TeV/nucleon, the LHC will carry the study of nuclear matter under extreme conditions and of the quark-gluon plasma into a new and unexplored energy domain.
Characterization of the facility:

High energy proton-proton collider, relativistic heavy ion collider.

Table of facility parameters:

Peak luminosities and center-of-mass energy for a number of possible ion beam combinations in the LHC. All numbers are estimates only.

<table>
<thead>
<tr>
<th>Beams</th>
<th>c.m.s. energy [TeV/A]</th>
<th>Luminosity [cm⁻²s⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb-Pb</td>
<td>5.5</td>
<td>10²⁷</td>
</tr>
<tr>
<td>Ar-Ar</td>
<td>6.3</td>
<td>10³⁰</td>
</tr>
<tr>
<td>O-O</td>
<td>7.0</td>
<td>3×10³¹</td>
</tr>
<tr>
<td>p-Pb</td>
<td>8.8</td>
<td>&gt; 1.5×10²⁹</td>
</tr>
<tr>
<td>p-Ar</td>
<td>9.4</td>
<td>&gt; 5×10³⁰</td>
</tr>
</tbody>
</table>

Brief and compact table with the facility’s major experimental instrumentation and its capabilities:

Three of the four major LHC experiments will make use of heavy ion beams: the dedicated general purpose heavy ion experiment ALICE and the two general purpose proton-proton experiments ATLAS and CMS.

Nature of user facility:

User facility

Program Advisory Committee/experiment proposals:

LHCC committee (12 CERN + 15 international members)

Number of active users and their origin:

c. 1000 users working primarily with heavy ions, ca 4000 working primarily in particle physics

Percentage of users, and percentage of facility use that come from inside the institution:

n/a

Percentage of users and percentage of facility use from national users:

n/a

Percentage of users and percentage of facility use from outside the country where your facility is located:

n/a

Fraction of the international users from outside geographical region:

c. 30%

User Group:

This and the remaining questions are probably not applicable to LHC as a specific facility.
CERN/ISOLDE

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Switzerland

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Facsimile: +41 22 767 89 90
E-mail: Maria.Garcia.Borge@cern.ch

International Laboratory

Main source of funding: contributions from member states (directly and through CERN budget).

Rolf-Dieter Heuer, Director

Head of the facility:

Maria Jose Garcia Borge

Scientific Mission and Research Programs:

ISOLDE is the CERN radioactive beam facility. It provides radioactive beams of around a thousand isotopes of 70 chemical elements at low energy (10-60 keV). These beams can be also post-accelerated to 5.5 MeV/u, starting from the Autumn of 2015 and to 10 MeV/u in the future, within the HIE-ISOLDE project. The main research topic is the structure of nuclei far from stability, complemented by significant activities in atomic physics, nuclear astrophysics and fundamental physics, as well as applications in material science, biophysics and medicine. The experiments include measurements of ground state properties (masses, moments, radii) and decay properties, as well as Coulomb excitation and transfer reactions with post-accelerated beams.

Technical facilities: Aerial photo of CERN with the linac2, PSB and ISOLDE facility highlighted.
Characterization of the facility:

ISOLDE is an Isotope Separator On Line type facility, where the radioactive nuclei are produced in a reaction of high energy and intensity protons with a thick target (see above). The protons are delivered by CERN’s Proton Synchrotron Booster (PSB in the photo) and a thousand different isotopes separated on-line are produced and ionized with one of twenty different types of target materials combined with three types of ion sources. The single charged ions of the different isotopes are magnetically separated.

Facility parameters:

<table>
<thead>
<tr>
<th>Primary beam</th>
<th>Protons: 1-1.4 GeV, 2 microA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivered species</td>
<td>&gt;850 isotopes of 70 elements</td>
</tr>
<tr>
<td>Beam energy</td>
<td>Low energy: 10-60 keV Post-accelerated to 5.5 MeV/u</td>
</tr>
<tr>
<td>Intensity</td>
<td>From below 1 up to $10^{11}$ ions/s</td>
</tr>
</tbody>
</table>

Detailed information: [www.cern.ch/isolde](http://www.cern.ch/isolde)

The facility’s major experimental instrumentation and its capabilities:

A considerable amount of travelling experiments are allocated in the first two beamlines, while the permanent setups are described below (going from right to left in the facility layout above).

<table>
<thead>
<tr>
<th>Setup</th>
<th>Technique</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications (GHM and GLM lines)</td>
<td>Perturbed angular correlation (PAC), emission channeling, Mossbauer spectr., photoluminescence</td>
<td>Local hyperfine fields probe by nuclei: material and biology studies</td>
</tr>
<tr>
<td>COLLAPS</td>
<td>Collinear laser and spectroscopy and beta-NMR</td>
<td>Nuclear radii, moments, spins</td>
</tr>
<tr>
<td>CRIS</td>
<td>Collinear Resonant Ionization Spectroscopy</td>
<td>Nuclear radii, moments, beam purification</td>
</tr>
<tr>
<td>VITO</td>
<td>PAC, beta-NMR</td>
<td>Material and biology studies</td>
</tr>
<tr>
<td>WITCH</td>
<td>Pennig trap and recoil spectrometer</td>
<td>Search scalar terms in weak interaction</td>
</tr>
<tr>
<td>ISOLTRAP</td>
<td>Penning trap mass spectrometry</td>
<td>High precision Nuclear masses</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>TAS</td>
<td>Total Absorption Spectrometer</td>
<td>Beta decay; nuclear deformations</td>
</tr>
<tr>
<td>IDS</td>
<td>Decay studies</td>
<td>Properties of excited states</td>
</tr>
<tr>
<td>NICOLE</td>
<td>Low-temperature nuclear orientation</td>
<td>Moments and details of decay</td>
</tr>
<tr>
<td>MINIBALL and T-REX</td>
<td>Coulomb excitation and 1- and 2-nucleon transfer reactions</td>
<td>Structure details, deformations, single-particle properties</td>
</tr>
</tbody>
</table>

**Nature of user facility:**

ISOLDE is a fully user facility

**Program Advisory Committee/experiment proposals:**

INTC (ISOLDE and neutron Time-of-Flight Experiments Committee) consisting of external referees with meetings 3 times per year

**Number of active users and their origin:**

About 450 users coming every year to participate in around 50 experiments

**Percentage of users, and percentage of facility use that come from inside the institution:**

n/a (international organization)

**Percentage of users and percentage of facility use from national users:**

n/a (international organization)

**Percentage of users and percentage of facility use from outside the country where your facility is located:**

About 99 % and 98 %, respectively

**Fraction of the international users outside of geographical region:**

Roughly 15 %

**User Group:**

There is no formal users group, but the users are organized through the ISOLDE Collaboration (13 member countries + CERN), which meets 3 times per year. The users meet further every winter at the ISOLDE Workshop.

**Number of a) permanent staff and b) temporary staff:**

a) No physicists, 13 technical staff

b) 7 physicists (and 1 secretary) paid by CERN and EU grants, 1 technical staff paid by CERN

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**

None at ISOLDE (occasional long-term visitors), but CERN has a theory department

**Number of postdoctoral researchers:**

2 research- and 2 applied-follows

**Number of graduate students resident at the facility:**

Typically 10 physics students

**Number of non-resident graduate students with thesis work primarily done at the facility:**

At a given time more than 50 graduate students, roughly 10-15 theses/year

**Involvement of undergraduate students in research (approximate average number at a given time):**

Some undergraduate students participate in experiments plus a dozen of undergraduates that join us as part of the summer student programme

**Special student programs:**

CERN has a summer student program for undergraduate students, in which ISOLDE participates actively (10-15 students/year)

**Future Plans:**

HIE-ISOLDE, the upgrade of energy of post-accelerated radioactive ions is ongoing with energy up to 5.5 in Autumn 2015 and later increase up to 10MeV/u. The expected increase in intensity of a factor of 6 in 2018 has prompted a design addressing improvement in beam purity, emittance and intensity for all beams. The design study is almost finished and it will be presented in spring 2014 for evaluation and gradual implementation.
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Telephone: +41 56 310 46 66
E-mail: useroffice@psi.ch

Direct Contact for Nuclear & Particle Physics http://www.psi.ch/ltp
Secretary of Laboratory for Particle Physics (LTP): A. VanLoon, Telephone +41 56 310 32 54
Beam-coordinator: C. Petitjean, Telephone +41 56 310 32 60, E-mail: claude.petitjean@psi.ch

Facility:
Isochronous cyclotron running at 50.6 MHz frequency and delivering 2.4 mA proton current at 590 MeV.
Secondary beams of $\pi^\pm$, $\mu^\pm$, ultra-cold n

Procedure to apply for Beamtime:
Submission of proposals.
Information on procedures available from http://www.psi.ch/ltp/user-information
Presentation in an open users meeting.
PAC meets once per year.

Programme Advisory Committee (current membership):
1 in-house, 3 national, 9 international members.

Main Instrumentation for Nuclear and Particle Physics Experiments:
Several high intensity and luminosity pion and muon beams. Source of ultra-cold neutrons derived from proton-induced spallation neutrons (high storage densities, low background).
Special high purity $\mu$-facility for measuring ultra-rare decays.

Main Fields of Nuclear Research:
Low energy pion and muon physics. Experiments with ultra-cold neutrons.

Main Fields of Other Research:
Muon Spin Resonance experiments at several $\mu$SR facilities.
Radiation hardness tests of materials and electronic components and circuits with high intensity proton, neutron, pion and photon beams.
OPTIS: cancer therapy on human eyes with protons.
Human cancer therapy with 250 MeV protons, using a new dedicated cyclotron and 2 large gantries.
Neutron scattering at spallation neutron source SINQ.
X-ray experiments at the 2.4 GeV electron storage ring (Swiss Light Source SLS).

Accommodation:
Guest house (72 rooms) on site.

Transportation:
Bus connection to Brugg railway station (~10 km).

Future Developments (under construction):
Construction; large additional constructions have generally been obtained through investment schemes operated by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek” (NWO); smaller investments are paid from the running budget.

Operation; the institute is jointly operated from base funding from the Rijksuniversiteit Groningen and mission and programmatic funding from the Stichting voor Fundamenteel Onderzoek der Materie (FOM) and Gesellschaft für Schwerionenforschung in Darmstadt, Germany. The latter funding is earmarked for research and development at FAIR/GSI.

Prof.dr. M.N. Harakeh

Head of the facility:
Head of AGOR Accelerator Group: Dr. S. Brandenburg

Scientific Mission and Research Programs:
KVI pursues high-quality, innovative, front-line scientific research in the fields of fundamental and applied subatomic and atomic physics in a broad sense and educates and trains (graduate) students and post-docs in an international environment preparing them for future careers in industry and academia. KVI actively stimulates and participates in interdisciplinary fields of research, both within and outside KVI, as well as undertakes application-oriented research together with industries, businesses and the public sector.

The main current and future research programmes are:
– Fundamental interactions and symmetries (performed at KVI)
– Nuclear structure and nuclear astrophysics (performed at GSI)
– QCD at low energies; exotic states of quarks and gluons and charmonium spectrum (performed with PANDA at FAIR/GSI)
– Astroparticle physics (performed at Auger, ANTARES/KM3NeT)
Technical facilities:

Figure 1: Aerial view of the KVI

Figure 2: Top view of the cyclotron vault and the experimental areas
Characterization of the facility:
Intermediate-energy superconducting cyclotron with (polarised) proton and deuteron beams as well as heavy-ion beams up to Pb.

The central facility of KVI is AGOR, a superconducting K=600 MeV cyclotron for the acceleration of light and heavy ions. The cyclotron is equipped with three external ion sources. Presently, there are three major experimental detection systems for nuclear research at KVI, which all three can be used in conjunction with ancillary equipment. A new facility called TRIµP, meant for trapping radioactive ions produced with AGOR, will be in full operation around end of 2007.

Facility Parameters:
AGOR facility parameters:
- maximum energy from bending limit $E/A = 600 (Q/A)^2$ MeV per nucleon;
- maximum energy from focussing limit $E/A = 190 Q/A$ MeV per nucleon;
- minimum energy 5 MeV per nucleon at $Q/A < 0.2$,
  35 MeV per nucleon at $Q/A = 0.5$,
  120 MeV per nucleon at $Q/A = 1$
- maximum intensity $\leq 10^{13}$ particles per second (pps) for light ions,
  $\leq 10^{12}$ pps for heavy ions, strongly dependent on ion species;
- proton polarisation 75 %;
- deuteron polarisation 70 %.

A broad range of isotopes (light ions as protons, but also heavy ions up to lead) is available (see Figure 3). In the coming years high-intensity beams will be developed (in particular for the TRIµP research programme).

Major experimental instrumentation and its capabilities:
- Big-Bite magnetic Spectrometer (BBS)
- Dual-mode magnetic separator TRIµP
- Magneto-optical traps
- Big Instrument for Nuclear-polarisation Analysis (BINA)
- Plastic Ball: a $4\pi$ detector system consisting of 815 phoswich detectors.
- SiLi Ball consisting of 20 solid-state detectors.
- EDEN: a neutron-detection array consisting of 48 liquid scintillator detectors.
- Clover detectors: a pair of high-purity Ge detectors.

Presently, the TRIµP facility is being built. Its purpose is to perform high-precision measurements to investigate physics beyond the Standard Model. The TRIµP magnetic dual separator has been installed and was successfully tested during 2004. Concurrently, a laser laboratory is being set up. The facility is expected to be ready for physics in 2006.

A special beam line has been set up with which radiobiology experiments pertinent to proton therapy can be performed. Another beam line is available for irradiation experiments.

Nature of user facility:
KVI is a user facility for the international scientific community. Under the EURONS collaboration of the EU, KVI offers support for transnational access of outside users to the AGOR facility. The AGOR facility is also available for commercial use by industries, businesses and the public sector.

Program Advisory Committee/experiment proposals:
Yes. Proposals from users will be evaluated on basis of their scientific merit, by the AGOR Programme Advisory Committee (PAC).

Number of actual, active users of the facility in a given year:
We list here the number of Principal Investigators (PI) for the last 3 years (2003-2005); if an experiment has more than 1 PI, it is being counted...
as 1 only. On the average every PI represents 5-7 (active) users.
2003: 13
2004: 9
2005: 18

**Percentage of users, and percentage of facility use that come from inside the institution:**
Almost all users from outside collaborate with in-house users; here we list the number of PI’s from inside the institution (as with the previous item, in case of more than 1 PI per experiment, we count just 1).
2003: 1 (15%)
2004: 4 (44%)
2005: 7 (39%)
The used beam time of the inside users is as follows:
2003: 37%
2004: 57%
2005: 35%

**Percentage of users and percentage of facility use from national users:**
Here we exclude the inside users
2003: 2 PI’s (15%), using 11% of the time
2004: 2 PI’s (22%), using 20% of the time
2005: 2 PI’s (11%), using 8% of the time

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
2003: 9 PI’s (70%), using 51% of the time
2004: 3 PI’s (34%), using 23% of the time
2005: 9 PI’s (50%), using 58% of the time

**Fraction of the international users from outside geographical region:**
0%

**User Group:**
Yes, 70

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**
a) Permanent scientific staff: 22
b) Temporary scientific staff: 28

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**
Permanent: 2
Postdoctoral: 1
Graduate students: 2

**Number of postdoctoral researchers:**
Post-docs: 3

**Number of graduate students resident at the facility:**
Graduate students: 24

**Number of non-resident graduate students with thesis work primarily done at the facility:**
0

**Involvement of undergraduate students in research (approximate average number per year):**
10

**Special student programs:**
Biannual FANTOM study weeks; FANTOM is an international research school with partner institutes at the universities of Groningen (KVI), Gent, Leuven, Münster, Orsay (Paris) and Uppsala.
KVI is setting up a research master programme *Atomic and SubAtomic Physics* together with the Department of Theoretical Physics of the University of Groningen and the University of Uppsala.
KVI together with the Astronomy department of the University of Groningen is setting up a joint European master programme *Advanced Instrumentation and Informatics in Astronomy and Physics*, for which an application will be submitted in the Erasmus Mundus programme. Anticipated partner universities are the universities of Leuven, Paris-Sud, Uppsala, Bonn/Bochum/Köln (through FZ Jülich) and Krakow.

**Future Plans:**
Presently, the TRIµP facility is being set up. With this facility, high-precision measurements will be performed to investigate physics beyond the Standard Model. The TRIµP magnetic dual separator has been installed and was successfully tested during the summer of 2004. Concurrently, a laser laboratory is being set up. In the coming years high-intensity beams will be developed with AGOR, in particular for the TRIµP programme.
Head of the facility:
Dr. Nigel Smith, Director, SNOLAB

Scientific Mission and Research Programs:
SNOLAB is an International Facility for Underground Science; it is an expansion of the existing facilities constructed for the Sudbury Neutrino Observatory (SNO) solar neutrino experiment. SNOLAB follows on the important achievements in neutrino physics achieved by SNO and other underground physics measurements. The primary focus of the science programme is those areas of nuclear and particle astrophysics that can be addressed only by using a very deep laboratory. Specific areas include solar neutrinos, supernova neutrinos, neutrino-less double beta decay and dark matter searches.

While particle astrophysics is the principle focus for SNOLAB, there is a growing interest in other scientific fields to exploit deep underground laboratories and their associated infrastructure. In particular, there has been interest expressed in the fields of Seismology and Geophysics interested in precision, long term measurements at depth and in the field of Biology where there is a growing interest in deep underground life.

Technical facilities:

*The SNOLAB underground facilities are located at the 6800 foot level of the Vale Creighton Mine and include the original SNO cavern*
The surface building provides clean room space, change facilities, meeting rooms and office space for the underground experiments.

Table of facility parameters:
The great depth at which SNOLAB is located is required to shield these sensitive detection systems from the ubiquitous cosmic radiations that bombard the surface of the planet. By placing 2km (6000m water equivalent) of rock between the detectors and the surface these cosmic rays are sufficiently attenuated, by a factor of 50 million down to one cosmic ray muon every day per 4m², that the rare and exquisite signals from the science of interest can be separated from the signatures from other backgrounds.

The facility includes a surface building which houses offices, conference rooms, IT systems, clean-rooms, electronics labs, warehousing and change rooms. The underground facility is located at a depth of 2070m and comprises 5000m² of clean room facility, at better than Class2000, including three large detector cavities. In addition to the required health and safety systems and user support services, support infrastructure for experiments within the underground laboratory include HVAC, electrical power, ultra-pure water, compressed air, radiological source control, radio-assay capability, chemistry lab, I.T. and networking, and materials handling and transportation. The very specific requirements of developing and operating experiments in an underground laboratory are supported by a staff of ~50 covering business processes, engineering design, construction, installation, technical support and operations. The SNOLAB scientific research group connects to the experiments and provides expert and local support, as well as undertaking research in its own right as full members of the research collaborations.

Program Advisory Committee/experiment proposals:
All Experiment LOI’s are submitted to SNOLAB to be reviewed by the Experiment Advisory Committee.

Number of active users and their origin:
Currently about 260 people use the SNOLB facility (includes faculty, RA’s, students and engineers) from more than 50 Institutions worldwide.

Percentage of users, and percentage of facility use that come from inside the institution:
Almost all users are external

Percentage of users and percentage of facility use from national users:
About 50% of the users are from Canada

Percentage of users and percentage of facility use from outside the country where your facility is located:
About 50% of the users are from outside Canada

Fraction of the international users outside of geographical region:
90% of users are from North America

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
There are no theoreticians employed at the facility.
Number of non-resident graduate students with thesis work primarily done at the facility:

~20

Involvement of undergraduate students in research (approximate average number at a given time):

~25
TRIUMF, CANADA
Vancouver, Canada

TRIUMF
4004 Wesbrook Mall
Vancouver, BC
V6T 2A3, Canada

Telephone: 604 222 1047
Facsimile: 604 222 3791
E-mail: sciencediv@triumf.ca

Joint Venture of Canadian Universities
Currently 11 full members and 7 associate members

Funded by the Canadian Federal Government under a contribution administered by the National Research Council of Canada (NRC). Buildings provided by the province of British Columbia

Federal Government contribution

Experimental program by the relevant Science Research Councils (Peer reviewed) (Natural Science and Engineering Council, Canadian Institute for Health Research, etc)

Dr. P. Young Chairman of the TRIUMF Board of Management

Head of the facility:
Mr. J. Hanlon, CEO/Chief Administrative Officer

Scientific Mission and Research Programs:

TRIUMF is Canada’s national laboratory for particle and nuclear physics. It is owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada with building capital funds provided by the Government of British Columbia. Its mission is:

• To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science;
• To act as Canada’s steward for the advancement of particle accelerators and detection technologies; and
• To transfer knowledge, train highly skilled personnel, and commercialize research for the economic, social, environmental, and health benefit of all Canadians.

TRIUMF was founded in 1968 by Simon Fraser University, the University of British Columbia (UBC), and the University of Victoria to meet research needs that no single university could provide. The University of Alberta joined the TRIUMF consortium almost immediately. There are currently eleven full members and seven associate members from across Canada in the consortium that governs TRIUMF.

Since its inception as a local university facility, TRIUMF has evolved into a national laboratory while still maintaining strong ties to the research programs of the Canadian universities. The science program has expanded from nuclear physics to include particle physics, molecular and materials science, accelerator physics, and nuclear medicine. TRIUMF provides research infrastructure and tools that are too large and complex for a single university to build, operate, or maintain.

Since its opening in 1969, the laboratory has received more than $1 billion of federal investment and $40 million from the Province of British Columbia. The provincial contributions fund the
buildings, which are owned by UBC and located on an 11-acre site in the south campus of UBC.

There are over 350 scientists, engineers, and staff performing research on the TRIUMF site. It attracts over 500 national and international researchers every year and provides advanced research facilities and opportunities to 150 students and post-doctoral fellows each year. In addition to the onsite program, TRIUMF serves as a key broker for Canada in global research in particle, nuclear, and accelerator physics. (Taken from TRIUMF’s 2010 – 2015 Five Year Plan).

Characterization of the facility:

Technical facilities:

- Intermediate energy proton (H⁻) Cyclotron (500MeV), 4 independent extracted beams: 150 μamps, 100 μamps, 60 μamps and 10 μamps.
- RFQ linac, Drift Tube Linac for Radioactive beams up to 1.8 MeV/u (ISAC-I)
- Superconducting Drift Tube Linac for RIB to 6 MeV/u (ISAC-II)
- 4 Low energy H⁻ cyclotrons: two high intensity machines (1 to 2 milliamp) 30 MeV and two 50 μamp at 42 MeV and 13MeV dedicated to isotope production for life sciences and medical applications

**Facility Parameters:**

Proton: 60-100MeV and 200 -500MeV 150 μamp

Pion: up to 300 MeV/c 10**7/sec

Muon: up to 150MeV/c 10**7/sec
Radioactive beams from ISOL facility ISAC: up to 6.0 MeV/u, mainly A<150, up to 10**8/sec (isotope dependant)

Major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRINAT</td>
<td>Neutral atom trap.</td>
</tr>
<tr>
<td>8π</td>
<td>25 Compton suppressed Germanium Detectors, plastic and thin silicon detector arrays.</td>
</tr>
<tr>
<td>GRIFFIN</td>
<td>16 Large volume Germanium Clover detector array replacing 8π(2014)</td>
</tr>
<tr>
<td>Polarizer</td>
<td>polarized low energy ion beams (currently 8Li,11Li, Na)</td>
</tr>
<tr>
<td>βNMR/βNQR</td>
<td>Depth resolved magnetic characterization of surfaces and interfaces</td>
</tr>
<tr>
<td>Laser-spectroscopy</td>
<td>Collinear laser spectroscopy beamline</td>
</tr>
<tr>
<td>TITAN</td>
<td>Penning trap for mass measurement and in-trap decay spectroscopy</td>
</tr>
<tr>
<td>Francium</td>
<td>Francium atom trapping facility</td>
</tr>
<tr>
<td>MTV</td>
<td>Mott-Scattering of electrons from polarized 8Li to thes T-violation</td>
</tr>
<tr>
<td>OSAKA</td>
<td>Polarized beta-decay spectroscopy setup</td>
</tr>
<tr>
<td>DRAGON</td>
<td>low energy recoil spectrometer and windowless gas target for radiative capture reactions.</td>
</tr>
<tr>
<td>TUDA</td>
<td>Segmented silicon detector array for low energy reaction studies</td>
</tr>
<tr>
<td>TIGRESS</td>
<td>12 Large volume segmented Germanium Clover detector array.</td>
</tr>
<tr>
<td>DESCANT</td>
<td>Neutron detector array for TIGRESS</td>
</tr>
<tr>
<td>IRIS</td>
<td>Solid hydrogen target reaction station</td>
</tr>
<tr>
<td>EMMA</td>
<td>Electromagnetic recoil spectrometer for ISAC II (2014)</td>
</tr>
</tbody>
</table>

μSR spectrometers for condensed matter research
Radiochemistry facilities for life science tracers development
Large Clean rooms for detector development and construction

Nature of user facility:
YES, by the funding agency.

Program Advisory Committee/ experiment proposals:
Yes, in fact three: Subatomic Physics, Molecular and Materials Science, and Life Sciences. The first two meet twice a year and the last meets once a year. The laboratory is also advised by a Policy and Planning Advisory Committee composed of leading Canadian researchers in relevant subject areas that provide strategic advice on overall program direction.

Number of actual, active users of the facility in a given year:
An average of 612 scientific visitors per year over the period 2008-2012 (repeat visitors only counted once).

Percentage of users, and percentage of facility use that come from inside the institution:
It is estimated that over half of the users come from outside the institution.

Percentage of users and percentage of facility use from national users:
On average 27% Canadian users

Percentage of users and percentage of facility use from outside the country where your facility is located:
On average 73% of the visitors come from outside Canada.

Fraction of the international users is from outside your geographical region:

<table>
<thead>
<tr>
<th>Geographical Region</th>
<th>Visitors</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>3</td>
<td>1%</td>
</tr>
<tr>
<td>Australia &amp; New Zealand</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Europe</td>
<td>164</td>
<td>37%</td>
</tr>
<tr>
<td>Asia</td>
<td>104</td>
<td>24%</td>
</tr>
<tr>
<td>North America</td>
<td>169</td>
<td>38%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>441</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>
User Group:
The TRIUMF User group has 317 registered members in 2013.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
The formal FTE staff complement of TRIUMF is about 350; including undergraduate students, graduate students, postdoctoral fellows, and temporary workers, the total is over 500

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
12

Number of postdoctoral researchers:
49

Number of graduate students resident at the facility:
35

Number of non-resident graduate students with thesis work primarily done at the facility:
12

Involvement of undergraduate students in research (approximate average number per year):
The average number of undergraduate students is approximately 75.

Special student programs:
High School: Research fellowships (2/y)
Undergraduate students: Summer research fellowships (5/y), summer research awards and Coop term (60/y), Graduate students: Summer Nuclear Institute: (40 students each summer), Journal club, Lake Louise Institute (mainly in Particle Physics)

Future Plans:
Facility upgrades:
Advanced Rare Isotope Laboratory (ARIEL):
  − 50 MeV, 10mA electron linac for photo production of rare isotopes (under construction)
  − Second proton beamline to ISAC (requested)

Ultra Cold Neutron facility
  − Spallation target with 40 μamp, UCN production target, EDM experiment
0.7 MV VAN DE GRAAFF ACCELERATOR
INSTITUTO DE FÍSICA, UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

Mexico City, Mexico

Instituto de Física, UNAM.
Circuito de la Investigación Científica s/n
Ciudad Universitaria
Coyoacán, México DF
C.P. 04510
México

Telephone: 00 52 55 56225029 / 52 55 56225005
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E-mail: luisrf@fisica.unam.mx
E-mail: miranda@fisica.unam.mx

Research Laboratory at the Physics Institute of the National University of Mexico

University grant
University and/or Federal Grants by short term research projects
Budget from the institute

Dr. Arturo Menchaca Rocha, Director
Instituto de Física, UNAM

Heads of the facility:
Dr. Luis Rodríguez Fernández
Dr. Javier Miranda Martín del Campo

Scientific Mission and Research Programs:
The main activity of the laboratory is research focused on three subjects:
i) Fundamental physics on phenomena related to interaction of low energy ion beams with matter.

ii) Low energy Ion beam analysis of materials using: Rutherford Backscattering Spectrometry, RBS, Nuclear Reaction Analysis, NRA, and Particle induced X-Ray Emission, PIXE.

iii) Ion irradiation of materials.

iv) Teaching modern physics.

Technical facility:
The main instrument of the laboratory is a High Voltage Inc. 0.7 MV Van de Graaff Accelerator model AN700 with three fully operational ion beam lines each with an analysis vacuum chamber. It is possible to produce H⁺, He⁺, N⁺, Ar⁺ ions by a RF ion source located in the high voltage terminal.
Characterization of the facility:
Low energy ion accelerator for material analysis and atomic physics.

Facility parameters:

<table>
<thead>
<tr>
<th>Beam species</th>
<th>Maximum Intensities</th>
<th>Range of energies</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺</td>
<td>2 µA</td>
<td>100-700 keV</td>
</tr>
<tr>
<td>He⁺</td>
<td>500 nA</td>
<td>100-700 keV</td>
</tr>
<tr>
<td>N⁺</td>
<td>500 nA</td>
<td>100-700 keV</td>
</tr>
<tr>
<td>Ne⁺</td>
<td>500 nA</td>
<td>100-700 keV</td>
</tr>
<tr>
<td>O⁺</td>
<td>500 nA</td>
<td>100-700 keV</td>
</tr>
<tr>
<td>Ar⁺</td>
<td>1 µA</td>
<td>100-700 keV</td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:
Three vacuum chambers for RBS, NRA and PIXE analysis.

User facility:
Scientists and research people from other institutes of the UNAM or other universities of the country may use the facility if they are associated with a member of the staff of the facility, mainly by a research project approved by the scientific committee of the laboratory. They may be considered also as external users when they have access to the laboratory by an external service, by short term contracts for a specific use (analysis or irradiation). Non-university institutions and industry are always considered as external users.

Program Advisory Committee/ experiment proposals:
The facility has a scientific committee which determines the feasibility of a research project in this laboratory. Any experimental proposal has to be sent to Dr. Luis Rodriguez Fernández or Dr. Javier Miranda.

Number of actual, active users of the facility in a given year:
During the last three years the facility has got 10 research scientists as regular users.

Percentage of users:
Users from the same institution: 85%
Users from other institutes and Mexican universities: 15%
Users from other countries: 0%

Formal groups in the facility:
There is one: the group GAMMAI (Group of Analysis and Modification of Materials by Ion Beams) is in charge of the management of the Van de Graaff Accelerator Laboratory. That group is composed by 8 research scientists and 4 technicians.

Permanent staff:
4 research scientists
2 technicians

Temporary staff:
4 undergraduate students
2 graduated students

Theoretical Staff employed at the facility:
No theoretical staff is employed at the facility.

Number of postdoctoral researchers:
None

Number of graduate students resident at the facility:
None

Number of non-resident graduate students with thesis work primarily done at the facility:
None

Involvement of undergraduate students in research:
4 undergraduate averaged during the last two years.

Special student programs:
Open laboratory days (One full day for university students, one for high school and secondary students). Guided visits for students (around 15 per year).
5.5 MV ACCELERATOR, INSTITUTO DE FISICA, UNAM

North America, Mexico, South of Mexico City, Main University Campus of UNAM

5.5 Accelerator
Instituto de Fisica, UNAM
Circuito de la Investigación Científica s/n
Ciudad Universitaria
Mexico DF 04510
Mexico

Laboratory of Pelletron Accelerator
Instituto de Fisica, UNAM
Apdo. postal 20-364
Mexico DF 01000
Mexico

Telephone: 00 52 55 56225043 / 56225055
Facsimile: 00 52 55 56225009 /56225046
E-mail: sil@fisica.unam.mx
E-mail: andrade@ fisica.unam.mx

Research laboratory of an institute of the national university

Mainly three sources of funding:
i) Federal grants for research projects (CONACyT-Mexico)
ii) University grants for short term research projects (UNAM)
iii) Budget from the institute.

Dr. Arturo Menchaca Rocha, Director
Instituto de Fisica, UNAM

Head of the facility:
Dr. Eduardo Andrade

Scientific Mission and Research Programs:
Scientific mission and main current and future research programs of the facility:
Interdisciplinary research projects mainly in material science that requires material analysis, the most important: Ion Beam. Analysis techniques have been established in this accelerator.

Technical facilities:
Van de Graaff 5.5 MeV accelerator for positive ions.
Characterization of the facility:
Single ended Van de Graaff electrostatic. The accelerator ion source is RF.

Facility Parameters
Beams H1, H2, He3, and He4, energy beam 1 to 5.5 MeV.

Facility major experimental instrumentation and capabilities:
Surface barrier detectors and associated nuclear electronics; also Si(Li) X’ray detector

User facility:
Yes

Program Advisory Committee/ experiment proposals:
Yes

Number of users:
10 users, mainly from the materials science related, to produce thin films using plasma methods

Percentage of users and percentage of the facility use (last year):
20% inside.

Percentage of users and percentage of the facility use from national users (average last years):
60% outside

Percentage of users and percentage of the facility use from foreign users (average last two years):
20% outside

Percentage of international users from outside of the geographical region (average last two years):
10% Europe, 10% USA.

Formal groups in the facility:
None

Permanent and temporary staff:
Permanent staff: 2
Temporary staff: 4 PhD students.
15 under-graduated students.

Theoretical staff:
No theoretical staff

Number of postdoctoral researches:
None

Number of graduated students resident at the facility
None

Number of non-resident graduate students with thesis work primarily done at the facility:
None

Involvement of the undergraduate student in research:
1 student

Special students programs:
This facility is used for teaching, basic experiments in nuclear physics by students from Science Faculty from National University.

Describe the future developments at the facility:
We will replace the 90 degrees analyzing magnet.
LABORATORY OF PELLETRON ACCELERATOR, INSTITUTO DE FISICA, UNAM

North America, Mexico, South of Mexico City
Main University Campus of UNAM

Laboratory of Pelletron Accelerator
Instituto de Fisica, UNAM
Circuito de la Investigación Científica s/n
Ciudad Universitaria
Mexico DF 04510
Mexico

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Telephone: 00 52 55 56225043 / 56225005
Facsimile: 00 52 55 56225009 /56161535
E-mail: sil@fisica.unam.mx
E-mail: karim@fisica.unam.mx

Research laboratory of an institute of the national university

Three main sources of funding:
i) Federal grants for research projects (CONACyT-Mexico).
ii) University grants for short term research projects (UNAM).
iii) Budget from the institute.

Dr. Arturo Menchaca Rocha, Director
Instituto de Fisica, UNAM

Head of the facility:
Dr. José Luis Ruvalcaba Sil

Scientific Mission and Research Programs:
The Pelletron laboratory is one of the most important laboratories of the National University of Mexico (UNAM), Mexico and of the Latin American countries. The main activity of the laboratory is research focused on three subjects:

i) Fundamental physics on phenomena related to interaction between ion beams and matter.

ii) Ion beam analysis of materials and its applications.

iii) Ion beam modifications of materials.

There is no other laboratory in Mexico with these three features. The research topics are determined and described in detail in the development program of the institute (IFUNAM, http://www.fisica.unam.mx/plan2003.pdf). The main research topics are:

1. Nuclear Reactions in Astrophysics

2. Thermoluminiscence properties of irradiated materials.
3. Atomic and molecular physics.
4. Development of analytical methods based on ion beam accelerators
5. Interdisciplinary applications of ion beam analysis (materials science, archaeology and arts, geology and soils, food, odontological materials, biomaterials, etc.).
6. Pollution and environmental studies.
7. Biological and medical tissues studies by ion beam analysis
8. Applications of ion beam dosimetry.
9. New materials and modification of surface properties by ion beam implantation and ion beam mixing.

Future research projects must fit the research frame of the institute. The revision of the program of research is carried out every three years or less, if necessary.

Under the actual research program it is considered the development of the following devices in the next future to complete and improve the researches.

a) A microbeam facility for materials characterization (biological, medical, nanomaterials, national heritage).

b) A WDX spectrometer for the study of ionization processes and X-ray emission by heavy ions and for analytical purposes.

**Technical facilities:**

The main instrument of the laboratory is a 3 MV Tandem Pelletron Accelerator with four fully operational ion beam lines. It is possible to produce ions from H to Au or even heavier (except noble gas from Ar). The maximum energy of the beam depends on ion charge and ion production cross sections. Two kinds of ion sources are available: A ion sputtering source for solids (SNICS) and a plasma radiofrequency (RF) source for gases (Alphatross).

One beam line is used mainly for measurements of astrophysical reactions and light isotopes separation while two beam lines may be used for ion beam analysis in vacuum or for non-vacuum measurements by an external beam set-up at the air atmosphere. The main analytical techniques are PIXE, RBS (including channeling) and PIGE but ERDA, PESA, XRF and NRA may also be carried out. Finally, one line is used for ion beam implantation and the modification of the surface properties of materials. Measurements on basics processes of interaction of heavy and light ion beams with materials may be done on most of the ion beam lines (e.g. ionization cross sections by heavy ions).

Low, medium and high vacuum equipment, high performance electronics devices, detectors of radiation (X-rays, Gamma rays, particles, UV and visible light), computers for the accelerator control and data acquisition are associated with the accelerator and represent a valuable part of the laboratory.

**Characterization of the facility:**

Low-Medium Energy Tandem Pelletron Accelerator (3 MV) for ion beam analysis and ion beam implantation.

**Facility Parameters**

The parameter for the most used ions:

* Intensity depends on ion charge.
Facility major experimental instrumentation and capabilities:

<table>
<thead>
<tr>
<th>Ion beam</th>
<th>Type and number of detectors</th>
<th>Main topics of research</th>
</tr>
</thead>
<tbody>
<tr>
<td>ion beam interaction’s phenomena</td>
<td>3</td>
<td>ionizations, scattering and nuclear reactions cross sections, nuclear</td>
</tr>
<tr>
<td>ion beam analysis</td>
<td>2</td>
<td>X-rays (4), Gamma-ray (5), Particles (6), PIXE, RBS, RBS-ESCA, PIXE, PESA, ERLA, ERLA,</td>
</tr>
<tr>
<td>ion beam implantation</td>
<td>1</td>
<td>Nuclear materials, new surface properties, metals, polymers, semiconductors, biomaterials</td>
</tr>
</tbody>
</table>

* Fundamental physics measurements are carried out also in the analytical beam lines

User facility:

Since the use of the laboratory require a high degree of specialization on ion beam accelerators, radiation production and management and its detection, the research staff of the Experimental Physics Department of the Instituto de Fisica represents the main official user of the facility. All the experiments are approved or rejected by a scientific committee who determine the research feasibility and if the experiments keep under the radiological security regulations for this laboratory.

Scientifics and research people from other institutes of the UNAM or other universities of the country may use the facility if they are associated to a member of the staff of the facility, mainly by a research project approved by the scientific committee of the laboratory. They may be considered also as external users when they have access to the laboratory by an external service, by short terms contract for a specific use (analysis or irradiation). Non-university institutions and industry are always considered as external users.

Program Advisory Committee/ experiment proposals:

The facility has a scientific committee who determine the feasibility of a research and if the experiments accomplish the radiological security regulations for this laboratory. The research topics and scientific applications are mainly determined by the frame-program of development and research of the institute.

Number of users:

Regular users from the research departments of the institute per month (average of the last three years): 14 research scientists.

Percentage of users and percentage of the facility use (last year): Institute regular users:

- 85%. Facility use:
  - 85% Users from other institutes and universities:
    - 10%. Facility use: 10% External users: 5%. Facility use: 5%

Percentage of users and percentage of the facility use from national users:

- Institute regular users: 85%. Facility use: 85% Users from other national institutes and universities: 15%. Facility use: 15%

Percentage of users and percentage of the facility use from foreign users:

- National users: 98%. Facility use: 95% Foreign users: 2%. Facility use: 5%

Percentage of international users from outside of the geographical region:

One. The group GAMMAI (Group of Analysis and Modification of Materials by Ion Beams) is in charge of the management of the Pelletron accelerator laboratory. It is composed by 8 research scientists and 4 technicians.

Permanent and temporary staff:

Permanent staff: 5 research scientists. 2 technicians. Temporary staff: 4 PhD students. 15 under-graduated students.

Theoretical staff:

No theoretical staff is employed at the facility but some theoretical groups have a close collaboration with the scientists of this facility.

Number of postdoctoral researches:

None during the last year.

Number of graduated students resident at the facility:

- 6 students (average last two years).
Number of non-resident graduate students with thesis work primarily done at the facility:
12 students (average last two years).

Involvement of the undergraduate student in research:
15 students (average last two years). Four or five students may participate in one experiment at the same time in the laboratory for some topics of research.

Special students programs:
Summer programs (between one and two months) organized by the Mexican Academy of Science and the UNAM program of science for young students (high school and university).
Open laboratory days (One full day for university students, one for high school and secondary students).
Guided visits for students (around 15 per year).

Future plans:
Under the actual research program it is considered the development of the following developments in the next future:

a) A micro-beam facility for materials characterization (biological and medical tissues, studies on nanomaterials, samples related to national heritage). The expected spatial resolution of the experimental set-up is 1µm.

b) A WDX spectrometer for the study of ionization processes and X-ray emission by heavy ions and for analytical purposes.

c) A new chamber for ion beam implantation. The main new features of this device concern to in situ characterization and the control of the sample temperature.
**4.5-MV TANDEM ACCELERATOR, OHIO UNIVERSITY**

Edwards Accelerator Laboratory  
Department of Physics and Astronomy  
Ohio University  
Athens OH 45701 USA

Telephone: (740) 593-1977  
Facsimile: (740) 593-1436  
E-mail: brune@ohio.edu  
http://inpp.ohiou.edu/~oual/

Construction: State of Ohio  
Operation: Ohio University  
(Research sponsored by the U. S. Department of Energy,  
Office of Science, National Nuclear Security Agency, and others)

Professor David Ingram, Chair  
Department of Physics and Astronomy

**Head of the facility:**  
Professor Carl R. Brune

**Scientific Mission and Research Programs:**

The John E. Edwards Accelerator Laboratory provides ion beams and the associated detection equipment for the study of nuclear reactions of interest for nuclear structure, nuclear astrophysics, materials science, inertial confinement fusion, nuclear energy, homeland security, and other applications. This research is performed by Ohio University students, faculty, and staff, as well as users from other universities and laboratories.

The education and training of undergraduate and graduate students is a fundamental mission of the laboratory. Physics and Astronomy majors utilize the accelerator in the required advanced undergraduate laboratory course and have the opportunity to work in the laboratory, including summer research and honors thesis research. Much of the research in the laboratory is carried out by graduate students working towards M.S. and Ph.D. degrees.

**Technical facilities:**

Please see [http://inpp.ohiou.edu/~oual/](http://inpp.ohiou.edu/~oual/) and associated links.

**Characterization of the facility:**

The 4.5-MV tandem accelerator is housed in the Edwards Accelerator Laboratory on the Ohio University campus in Athens, Ohio. A Cs sputter source is available for producing H, D, Li, and heavier ion beams. Beams of $^3$He and $^4$He are provided by a duoplasmatron ion source. Nanosecond beam pulsing is possible. Standard equipment for charged-particle, neutron, and gamma-ray detection are available. A well-shielded 30-m tunnel for neutron time-of-flight experiments is a unique feature of the laboratory. Through use of a beam swinger, it can measure neutrons over a wide range of reaction angles.
Facility Parameters:
Accelerated energies and currents:
\[ ^{1,2}H \text{ – 0.5 MeV to 9.0 MeV, 10 µA DC} \]
\[ ^{3,4}He \text{ – 1 MeV to 13.5 MeV, 1 µA DC} \]
Heavier ions – varies
All beams can be run as nanosecond-pulsed beams or continuous beams.

Major experimental instrumentation and its capabilities:
A well-shielded 30-m tunnel and many NE-213 and \(^{6}\)Li-glass scintillators are available for neutron time-of-flight experiments. Neutron production is available via the (d,n) reaction on solid and gaseous deuterium or tritium targets. Gamma-ray detection equipment includes Ge, BGO, LaBr, and NaI detectors. Charged-particle detection equipment includes a scattering chamber optimized for Rutherford Backscattering and another chamber for time-of-flight measurements with flight paths of up to 2 m. The W.M. Keck Thin Film Analysis Facility consists of an integrated set of UHV chambers that includes PVD and CVD deposition facilities with MeV ion beam analysis (RBS, NRA, ERS, channeling), LEED, and electron spectroscopy (Auger, XPS, UPS).

Nature of user facility:
Several groups visit the laboratory each year to conduct experiments. Many outside groups utilize our unique neutron time-of-flight capabilities. The arrangements with outside users may or may not be collaborative. In some cases, outside users pay for beam time.

Program Advisory Committee/Experiment Proposals:
Arrangements to accommodate users can be made by contacting Professor Carl R. Brune.

Number of actual, active users of the facility in a given year:
Several outside user groups utilize the facility each year.

Percentage of users, and percentage of facility use that come from inside the institution:
Inside users: 75% and 75%.

Percentage of users and percentage of facility use from national users:
National users (including Canada) 20% and 20%.

Percentage of users and percentage of facility use from outside the country where your facility is located:
5% and 5%.

Fraction of the international users outside geographical region:
The international users in the past 5 years have come from Norway.

User Group:
We are a member of the Association for Research at University Nuclear Accelerators (ARUNA). See [http://aruna.physics.fsu.edu/](http://aruna.physics.fsu.edu/).

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 9
b) 6

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
The Nuclear Theory Group in the Physics and Astronomy Department presently includes 4 faculty, 3 postdoctoral researchers, and 4 graduate students.

Number of postdoctoral researchers:
Normally, 1-2 postdoctoral researchers in the laboratory are supported by grant funding.

Number of graduate students resident at the facility:
There are presently 7 graduate students resident at the laboratory who are performing research at the facility. The laboratory also hosts approximately 6 graduate students who are performing thesis work elsewhere.

Number of non-resident graduate students with thesis work primarily done at the facility:
None at this time.

Involvement of undergraduate students in research (approximate average number per year):
Typically 1-2 students during the academic year, increasing to 3-4 during the summer.

Special student programs:
Senior Physics majors may conduct Honors Thesis research in the laboratory.

Future Plans:
The accelerator was recently upgraded to a Pelletron charging system. Improvements to the data acquisition system are presently underway.
7-MV ACCELERATOR, UNIVERSITY OF KENTUCKY

North America

Chemistry-Physics Building
University of Kentucky
Lexington, KY USA

Department of Physics & Astronomy
505 Rose Street
University of Kentucky
Lexington, KY 40506-0055 USA

Telephone: (859) 257-6707
(859) 257-4005
Facsimile: (859) 323-9985
E-mail: yates@uky.edu
http://www.pa.uky.edu/accelerator

Construction: Commonwealth of Kentucky
Operation: University of Kentucky
Nuclear Structure and Neutron-Induced Reactions
(Sponsored by the U. S. National Science Foundation and Department of Energy,
Office of Nuclear Energy, Nuclear Energy University Programs)

Prof. Sumit Das, Chair
Department of Physics and Astronomy

Head of the facility:
Prof. Steven W. Yates

Scientific Mission and Research Programs:
The primary mission is to carry out basic research in nuclear science, with a special emphasis on neutron-induced reactions. An equally important goal is to provide high-quality graduate education to candidates for M.S. and Ph.D. degrees in nuclear physics and nuclear chemistry. A secondary mission is to search for applications, which contribute to national security or energy independence.

Current research is focused primarily on examining the structure of complex nuclei and on the determination of neutron scattering cross sections of importance for advanced reactors. Some work on topics in nuclear astrophysics is also ongoing.

Future research will likely focus more strongly on acquiring data which contributes to our understanding of fundamental symmetries and nuclear astrophysics, but a strong emphasis on nuclear structure will continue.

Technical facilities:
Please see http://www.pa.uky.edu/accelerator/ and associated links.

Characterization of the facility:
The single-ended electrostatic accelerator is housed in a cylinder tower adjacent to the Chemistry-Physics Building. Only light ions are accelerated, mostly with nanosecond pulsed/bunched beams.

Pulse widths:
protons – 0.8 ns;
deuterons and He ions – 1.3 ns

Sub-nanosecond pulsing is available through post-acceleration bunching.
Facility Parameters:

Accelerated energies:
- protons – 0.4 MeV to 7.0 MeV
- deuterons – 0.4 MeV to 7.0 MeV
- $^3$He$^+$ ions – 1 MeV to 7.0 MeV
- $^4$He$^+$ ions – 1 MeV to 7.0 MeV

All beams can be run as nanosecond-pulsed beams or continuous beams. Pulsed beams have average intensities of 1 to 5 microamps, and continuous beams can be up to 30 microamps.

Major experimental instrumentation and its capabilities:

The laboratory has shielded neutron and gamma-ray detectors for neutron scattering or neutron-producing reactions, such as (d,n) or ($^3$He,n). A four-detector HPGe array and collimated neutron fluences are used for gamma-ray coincidence experiments in neutron-induced reactions.

Nature of user facility:

Unofficially, several groups visit each year to collaborate on experiments, because of our special capabilities in neutron-induced and neutron-producing reaction studies. Commercial firms can purchase beam time.

Program Advisory Committee/Experiment Proposals:

Arrangements are made to accommodate users by contacting Prof. Steven W. Yates.

Number of actual, active users of the facility in a given year:

Over the last few years, several research teams have visited to carry out experiments of their own design.

University of Dallas, Prof. S. F. Hicks and undergraduate students
U. S. Naval Academy, Prof. J. R. Vanhoy and undergraduate students
University of Guelph, Prof. P. E. Garrett, graduate students and postdoctoral scholars
Georgia Institute of Technology, Prof. J. L. Wood
Institute of Isotopes, Budapest, Hungary, Prof. Jesse L. Weil (emeritus)

Percentage of users, and percentage of facility use that come from inside the institution:

Inside users: 80%

Percentage of users and percentage of facility use from national users:

National users (including Canada) 15%

Percentage of users and percentage of facility use from outside the country where your facility is located:

5% outside the U. S.

Fraction of the international users outside geographical region:

All are from Europe and Canada.

User Group:

No formal users’ group exists.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) Three
b) Two senior professors full time

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

One nuclear theorist in the Physics Department with experience in low-energy phenomena

Number of postdoctoral researchers:

Normally, two postdoctoral scholars are supported by grant funding.

Number of graduate students resident at the facility:

Two

Number of non-resident graduate students with thesis work primarily done at the facility:

All thesis and dissertation students become resident at the facility.

Involvement of undergraduate students in research (approximate average number per year):

Typically one student, plus those who visit with outside collaborators.

Special student programs:

Graduate students from the University of the Western Cape in Cape Town, South Africa will soon be working in the laboratory.

Future Plans:

There are no expansion plans; the last major accelerator upgrade was in 1990. The new data acquisition system will be expanded.
88-INCH CYCLOTRON AT
LAWRENCE BERKELEY NATIONAL LABORATORY

Berkeley, CA USA

MS88R0192, LBNL
1 Cyclotron Rd
Berkeley, CA 94720

Telephone: (510)-486-5088
Facsimile: (510)-486-7983
E-mail: mbjohnson@lbl.gov (Research Coordinator)

Department of Energy Office of Science for Nuclear Physics and National Reconnaissance Office
Operating funds: 60% DOE, 20% USAF-SMC, 20% National Reconnaissance Office

Dr. Paul Alivisatos

Head of the facility:
Dr. Larry Phair

Scientific Mission and Research Programs:
The 88-Inch Cyclotron (operated by the Nuclear Science Division at LBNL) is the home of the Berkeley Accelerator Space Effects (BASE) facility and supports a local research program in nuclear science. The National Security Space (NSS) community and researchers from other government, university, commercial, and international institutions use the BASE facility to understand the effect of radiation on microelectronics, optics, and materials for spacecraft. Research programs in heavy element physics and chemistry, nuclear structure, fundamental interactions and symmetries, technology research and development, and radiation biology by local LBNL and UC Berkeley scientists and students are supported. Major instrumentation developed at the Cyclotron includes GRETINA, the next generation Gamma Ray Energy Tracking Array, and VENUS, a 3rd generation superconducting ECR ion source which is the prototype for the FRIB driver ion source.

Technical facilities:
Characterization of the facility:
The 88-Inch Cyclotron accelerates both light and heavy ions to medium energies.

Facility Parameters:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Energy range (AMeV)</th>
<th>Max intensity (nA)</th>
<th>Primary uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>protons</td>
<td>1-55</td>
<td>20000</td>
<td>BASE, nuclear science</td>
</tr>
<tr>
<td>Deuterons</td>
<td>1-32.5</td>
<td>20000</td>
<td>Neutron production, nuclear science</td>
</tr>
<tr>
<td>$^3$He</td>
<td>1-45</td>
<td>20000</td>
<td>Nuclear science</td>
</tr>
<tr>
<td>$^4$He</td>
<td>1-32.5</td>
<td>20000</td>
<td>Nuclear science, BASE</td>
</tr>
<tr>
<td>Medium Ions</td>
<td>1-32.5 for Q/A=1/2</td>
<td>10000</td>
<td>Nuclear science, radiation biology, BASE</td>
</tr>
<tr>
<td>Heavy Ions (A=40-180)</td>
<td>Maximum energy depends on Q/A</td>
<td>30000</td>
<td>Nuclear science, BASE</td>
</tr>
<tr>
<td>Heavy Ion cocktails</td>
<td>4.5 (A=8-209), 10(A=8-136), 16 (A=8-86) AMeV cocktails</td>
<td>BASE</td>
<td></td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Use/capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkeley Gas-Filled Separator (BGS) + Recoil Transfer Chamber (for chemistry of the heaviest elements)</td>
<td>A He-filled separator which has high efficiency for normal kinematic experiments for heavy element physics and chemistry</td>
</tr>
<tr>
<td>Facility for Exotic Atom Trapping (FEAT)</td>
<td>A magneto-optical trap for neutral radioactive atoms; for beta-neutrino</td>
</tr>
</tbody>
</table>

Nature of user facility:
The Cyclotron is supported to run a local nuclear science program and a national program for radiation effects testing using the BASE facility.

Program Advisory Committee/experiment proposals:
No

Number of actual, active users of the facility in a given year:
301 (FY12 numbers)

Percentage of users, and percentage of facility use that come from inside the institution:
15.6% of users
58.3% of facility use (FY12 numbers)

Percentage of users and percentage of facility use from national users:
0% (not a National User Facility)

Percentage of users and percentage of facility use from outside the country where your facility is located:
8.6% of users (FY12 numbers)
0% of facility use

Fraction of international users outside of geographical region
100%

User Group:
No

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
  a) 60 total
  b) 26

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
0

Number of postdoctoral researchers:
8
Number of graduate students resident at the facility:
6

Number of non-resident graduate students with thesis work primarily done at the facility:
2

Involvement of undergraduate students in research (approximate average number per year):
4 during school year; 6 during summer

Special student programs:
1) We provide research experiences to undergraduate students through DOE programs.
2) We are collaborating with the UCB Nuclear Engineering Department on ways to provide undergraduates hands-on research experience.
3) We provide research experiences to high school students through the LBNL summer high school programs.

Future Plans:
1) Mass measurement of heavy elements from a combination of BGS, RF gas catcher, RFQ trap and mass analyzer.
2) A neutron beam line is under development which will provide quasi-monoenergetic up to 30 MeV.
ATLAS (THE ARGONNE TANDEM LINAC ACCELERATOR SYSTEM)  
ARGONNE NATIONAL LABORATORY (ANL)

Darien, Illinois (Chicago Metropolitan Area)

Physics Division,  
Argonne National Laboratory  
9700 S. Cass Ave.  
Building 203  
Argonne, Illinois 60439

Telephone: 630-252-4004  
Fascimile: 630-252-3903  
Email: Janssens@anl.gov

Department of Energy, Office of Science, Nuclear Physics

Department of Energy Office of Nuclear Physics SC-26  
Dr. Eric Isaacs, Director, Argonne National Laboratory

Heads of the facility:

Dr. Robert V. F. Janssens, Director, Physics Division  
Dr. Guy Savard, ATLAS Scientific Director  
Dr. Richard Pardo, Chief of ATLAS Operations

Scientific Mission and Research Programs:

The mission of the ATLAS facility at Argonne is to enable research of the highest quality by its users and staff, especially probing the properties of atomic nuclei, through utilizing the capabilities of the accelerator and research equipment in a safe and efficient manner, with the associated responsibility of research and development in accelerator science and in the techniques that are required to accomplish its scientific goals.

The major scientific goals of the ATLAS research program are: (a) understanding of the stability and structure of nuclei as many-body systems built of protons and neutrons bound by the strong force, (b) exploring the origin of the chemical elements and their role in shaping the reactions that occur in the cataclysmic events of the cosmos, (c) understanding of the dynamics governing interactions between nuclei at energies in the vicinity of the Coulomb barrier, and (d) testing with high accuracy the fundamental symmetries of nature by taking advantage of nuclei with specific properties.

To reach these goals, major research topics included:

1. The development of beams of short-lived isotopes and their subsequent use for measurements of astrophysics interest and for nuclear structure and reaction studies;
2. The production and characterization of nuclear structure away from the valley of stability including nuclei at the very limits of stability, i.e., nuclei at and beyond the proton drip-line, on the neutron-rich side of the valley of stability, and in the region with Z > 100;
3. The study of the nature of nuclear excitations as a function of mass, proton or neutron excess, spin and temperature; with emphasis on characteristics such as nuclear shapes, the interplay between degrees of freedom, changes in shell structure;
4. The use of traps for high-precision mass measurements for astrophysics and for searches of physics beyond the standard description of the weak interaction.

Smaller scale, complementary efforts exploit the exceptional and often unique capabilities of ATLAS: for example, the irradiation of samples for materials research, developing accelerator mass spectrometry techniques for applications in
environmental studies, oceanography, astrophysics, fundamental interactions, and any other area of basic science where they apply, and accelerator research experiments.

Technical facilities:

Figure 1. ATLAS Floor Plan

Characterization of the facility:
Superconducting Heavy-ion Linac

Facility Parameters:
ATLAS can provide beams of all stable elements from protons to uranium, and a selection of radioactive beams produced through either in-flight production for light beams close to stability or with the CARIBU facility for neutron-rich, mid-mass isotopes.

The ATLAS superconducting linac has been upgraded to allow high heavy-ion beam intensity, essentially limited by ion source performance, at Coulomb barrier energies. The maximum beam intensity can exceed 10 pμA and maximum values for various types of source feed material are given in Table 1.

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>1 pμA</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases</td>
<td>10-55</td>
<td>Ne, Ar, Kr, Xe, O, N, ...</td>
</tr>
<tr>
<td>Non-refractory Metals and Non-metals Tboil&gt; 1500ºC</td>
<td>1.0-11</td>
<td>Si, S, Ni, Fe, Ce, Ca, U...</td>
</tr>
<tr>
<td>Refractory Metals Tboil &gt; 1500 ºC</td>
<td>~1</td>
<td>Mo, Ti, Zr, V, Pt, Ir ...</td>
</tr>
<tr>
<td>Low Boiling Point Heavy Metals</td>
<td>0.6 – 2.5</td>
<td>Au, Pb, Bi, ...</td>
</tr>
</tbody>
</table>

Table 1. Maximum currents available at ATLAS for various types of source feed material.

The intensities for ions lighter than 12C are restricted by administrative constraints based on radiation safety considerations. When needed,
isotopically enriched material is used at no direct cost to the user. The consumption rate varies with the element. For $^{48}\text{Ca}$, for example, for a beam of 15 pnA on target, the consumption rate is typically 0.05 mg/h.

The maximum beam energy available depends on the charge-to-mass ratio of the species extracted from the ECR ion sources. The maximum energy that can be attained at ATLAS, with or without stripping, for the various stable isotopes available is shown in Figure 2. The intensity available after stripping is typically 20% of the unstripped intensity.

The in-flight and batch-mode produced radioactive beams are typically light beams, up to A~50, one or two neutrons away from stability. Typical beams that have been used in the past are presented in Table 2.

Beams of mid-mass, neutron-rich isotopes are available at low or Coulomb barrier energy via the CARIBU upgrade of ATLAS. These isotopes are obtained through $^{252}\text{Cf}$ fission and converted into a beam by a gas catcher system. Yields for a 1 Ci $^{252}\text{Cf}$ source are given in Figure 3. Reaccelerated CARIBU beams have essentially the same properties as stable beams accelerated through ATLAS.

![Figure 2. Maximum beam energy from ATLAS as a function of ion mass for two stripping assumptions. In general stripped beams will have approximately 20% of the intensity of unstripped beams.](image)
Table 2. Energy and production rates for in-flight and batch-mode produced radioactive beams at ATLAS. In some cases, the allowed maximum radiation may limit primary beam current.

<table>
<thead>
<tr>
<th>Ion</th>
<th>Half-Life</th>
<th>Reaction</th>
<th>Intensity (ions/sec/pnA)</th>
<th>Opening Angle (degrees)</th>
<th>Production Energy (MeV)</th>
<th>Max. Rate (ions/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^4$He</td>
<td>0.807 sec</td>
<td>d($^7$Li,$^4$He)$^4$He</td>
<td>150</td>
<td>19</td>
<td>75</td>
<td>$1 \times 10^4$</td>
</tr>
<tr>
<td>$^8$Li</td>
<td>0.838 sec</td>
<td>d($^7$Li,$^4$Li)p</td>
<td>2000</td>
<td>11</td>
<td>71</td>
<td>$1.5 \times 10^5$</td>
</tr>
<tr>
<td>$^8$B</td>
<td>0.770 sec</td>
<td>$^7$He($^7$Li,$^3$B)n</td>
<td>10</td>
<td>13</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>$^{16}$C</td>
<td>19.29 sec</td>
<td>p($^6$Li,$^{16}$C)n</td>
<td>540</td>
<td>4.5</td>
<td>120</td>
<td>$5 \times 10^4$</td>
</tr>
<tr>
<td>$^{17}$C</td>
<td>20.385 min</td>
<td>p($^6$B,$^{17}$C)n</td>
<td>2300</td>
<td>4.5</td>
<td>105</td>
<td>$2 \times 10^5$</td>
</tr>
<tr>
<td>$^{14}$O</td>
<td>70.606 sec</td>
<td>p($^7$Li,$^{14}$O)n</td>
<td>1200</td>
<td>2.9</td>
<td>170</td>
<td>$1 \times 10^5$</td>
</tr>
<tr>
<td>$^{15}$C</td>
<td>2.45 sec</td>
<td>d($^1$C,$^{15}$C)p</td>
<td>24000</td>
<td>5.4</td>
<td>96</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>$^{15}$N</td>
<td>7.13 sec</td>
<td>d($^{13}$N,$^{14}$N)p</td>
<td>30000</td>
<td>5.4</td>
<td>70</td>
<td>$3 \times 10^6$</td>
</tr>
<tr>
<td>$^{17}$F</td>
<td>64.49 sec</td>
<td>d($^7$Li,$^{17}$F)n</td>
<td>20000</td>
<td>4.5</td>
<td>-90</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>$^{19}$O</td>
<td>26.9 sec</td>
<td>d($^7$O,$^{17}$O)p</td>
<td>10000</td>
<td>4.7</td>
<td>145</td>
<td>$2 \times 10^5$</td>
</tr>
<tr>
<td>$^{21}$Na</td>
<td>22.48 sec</td>
<td>d($^{20}$Ne,$^{21}$Na)n</td>
<td>4000</td>
<td>4.0</td>
<td>113</td>
<td>$2 \times 10^6$</td>
</tr>
<tr>
<td>$^{25}$Al</td>
<td>7.183 sec</td>
<td>d($^{24}$Mg,$^{25}$Al)n</td>
<td>1000</td>
<td>3.7</td>
<td>204</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>$^{37}$K</td>
<td>1.226 sec</td>
<td>d($^{36}$Ar,$^{37}$K)n</td>
<td>1200</td>
<td>2.2</td>
<td>280</td>
<td>1 $\times 10^5$</td>
</tr>
<tr>
<td>$^{18}$F</td>
<td>109.77 min</td>
<td>batch.</td>
<td></td>
<td></td>
<td></td>
<td>6 $\times 10^6$</td>
</tr>
<tr>
<td>$^{24}$Ti</td>
<td>59 yr</td>
<td>batch</td>
<td></td>
<td></td>
<td></td>
<td>2 $\times 10^6$</td>
</tr>
<tr>
<td>$^{59}$Ni</td>
<td>6.10 day</td>
<td>batch</td>
<td></td>
<td></td>
<td></td>
<td>5 $\times 10^4$</td>
</tr>
<tr>
<td>$^{56}$Co</td>
<td>77.12 day</td>
<td>batch</td>
<td></td>
<td></td>
<td></td>
<td>2 $\times 10^5$</td>
</tr>
</tbody>
</table>

Figure 3. Fission yield distribution for a 1 Ci $^{252}$Cf source in ions/s. Stopped beam total efficiency to target is approximately 30%. For accelerated beams with ATLAS, total efficiency to target, including charge breeding efficiency, is approximately 5%.
Major experimental instrumentation and its capabilities:

**Major Equipment:**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragment Mass Analyzer (FMA)</td>
<td>Recoil separator for reaction products. The focal plane instrumentation includes a large variety of detectors (Si DSSD, PPAC, ionization chamber, tape transport, etc.).</td>
</tr>
<tr>
<td>Gammasphere</td>
<td>The national gamma-ray facility of 110 Compton-suppressed Ge detectors. The facility, now operating with digital electronics, can be used in conjunction with the FMA as well as on a separate beam line.</td>
</tr>
<tr>
<td>HELIOS: Helical Orbit Spectrometer</td>
<td>A superconducting solenoidal spectrometer with uniform axial field for 'inverse kinematics' nuclear structure studies.</td>
</tr>
<tr>
<td>Area II Split pole spectrograph</td>
<td>Dedicated for use with the Penning trap systems below.</td>
</tr>
<tr>
<td>Split pole spectrograph</td>
<td>Used primarily in astrophysics, AMS Measurements.</td>
</tr>
<tr>
<td>In-flight RIB production target</td>
<td>System of cooled gas cells or solid targets combined with a large bore superconducting solenoid and a resonator, used for the production of rare isotope beams for astrophysics and nuclear structure research.</td>
</tr>
<tr>
<td>Canadian Penning Trap (CPT)</td>
<td>An instrument for high-precision mass measurement that includes a gas catcher system to slow down reaction products and transform them into slow moving 1+ ions, an RF quadrupole trap for weak interaction studies or a general purpose station for beta-decay investigations.</td>
</tr>
<tr>
<td>Advanced Penning Trap (APT) system</td>
<td>High-field isobar separator system with very high mass resolution based on a linear Penning trap, injecting either an RF quadrupole trap for weak interaction studies or a general purpose station for beta-decay investigations.</td>
</tr>
<tr>
<td>Atom Trap</td>
<td>Laser based atom trap systems at present dedicated to measurements of charge radii of various He atoms.</td>
</tr>
<tr>
<td>General purpose scattering chamber</td>
<td>Includes annular and rectangular counters and associated electronics.</td>
</tr>
<tr>
<td>Large array of double-sided Si strip detectors</td>
<td>An array of detectors for decay spectroscopy including Ge &quot;clover&quot; detectors, and Si detectors for electron spectroscopy.</td>
</tr>
<tr>
<td>X-array</td>
<td></td>
</tr>
</tbody>
</table>

**General-purpose beam lines**

Two fully instrumented beam lines for equipment brought in by outside users.

**Nature of user facility:**

DOE Designated National User Facility

**Program Advisory Committee/experiment proposals:**

Yes, PAC meets on average twice a year.

**Number of actual, active users of the facility in a given year:**

Typically 200-250 users are present at ATLAS for an experiment each year. Including users on approved proposals, the number of users is typically 390 - 420 each year.

**Percentage of users and percentage of facility use that come from inside the institution:**

21% of the users are internal, 37% of beam time (2012 numbers)

**Percentage of users and percentage of facility use from national users:**

50% of users, 42% of beam time (2012 numbers)

**Percentage of users and percentage of facility use from outside the country where your facility is located:**

29% of users, 31% of beam time (2012 numbers)

**Fraction of the international users outside geographical region:**

82.4%

**User Group:**

Yes, 453 active user appointments, group represented by an executive committee.

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**

Physics Div. Permanent Staff = 74

Temporary Staff = 14 Postdocs, 16 resident grad students, 19 active emeritus staff

As subsets of the above:

Operations & Accelerator Dev. Perm. Staff = 29,

Temp. Staff = 1 Postdoc., Vis. Sci.= 1, resident grad student =1, 4 active emeritus staff
Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

Physics Div. Permanent Staff = 5; Postdoctoral = 3

Number of postdoctoral researchers:

Operations & Accelerator Development = 3
Low Energy Research = 6
Medium Energy Research = 3

Number of graduate students resident at the facility:

8

Number of non-resident graduate students with thesis work primarily done at the facility:

20

Involvement of undergraduate students in research:

30-40/year. The number varies considerably through the year peaking during the summer months.

Special student programs:

Graduate Programs
Laboratory-Graduate Research Appointments
Guest Graduate Appointments
Thesis-Parts Appointments
Research Aide Appointments
International Student Exchange Program
Cooperative Education
Undergraduate Programs
Fall Science Undergraduate Laboratory Internships
Spring Science Undergraduate Laboratory Internships
Summer Science Undergraduate Laboratory Internships
Community College Student Internships
Pre-college Program
Pre-Service Teacher (PST) Program
Research Aide Appointments
Cooperative Education
Symposium for Undergraduates in Science, Engineering, & Mathematics
Faculty and Student Team (FAST) Fellowships

Future Plans:

New initiatives:

AGFA, a large acceptance gas-filled spectrometer, will be used to study rare processes. It combines very large acceptance with a large distance between target and first quadrupole so that the full Gammasphere array can be accommodated around the spectrometer target location. This results in a very large gamma-recoil coincidence efficiency ideally suited to spectroscopic studies in the heavy element region.

AIRIS, a new recoil separator to increase the intensity and purity of the in-flight produced radioactive beams. AIRIS will consist of a high power production target followed by a magnetic chicane and a superconducting RF rebuncher to focus and select the isotopes of interest. It will be located in the main beamline, right after the superconducting linac so that the separated radioactive beams can be transported to a large number of experimental areas.
CENPA
Box 354290
Seattle, WA 98195

Telephone: 206 543 4080
Facsimile: 206 685 4634
Email: rghr@uw.edu
http://www.npl.washington.edu

General University Information:
www.washington.edu

The University of Washington is a major research university situated on a beautiful campus in Seattle in the Pacific Northwest. The UW – “U-Dub” – receives the second largest amount of federal research funding of all US universities. Six UW scientists have won Nobel Prizes, including our Hans Dehmelt, 1989 Nobel Laureate in Physics, now retired.

Nuclear Physics at UW:
The UW is a unique center for nuclear physics. It is home to the national Institute for Nuclear Theory (INT), and to the Center for Experimental Nuclear Physics and Astrophysics (CENPA), one of DOE’s Centers of Excellence. In addition a leading nuclear theory group exists within the Department of Physics. The Department of Physics, INT, and the Astronomy Department share a spacious new building, which encourages collaboration. CENPA has its own laboratories including an FN tandem accelerator in the North Physics Laboratory across campus.
intense source of radioactive $^6$He atoms in the world to use in conjunction with laser traps to search for new physics that would be observable in beta decay. Delicate torsion balances are being used to explore such exotic issues as dark matter, axions, general relativity, and extra dimensions.

Nuclear theorists in the Department are addressing a wide range of problems, such as the use of fundamental QCD lattice-gauge theory to calculate the properties of real nuclei.

The Institute for Nuclear Theory hosts programs and workshops to advance the frontiers of nuclear science and its intersections with astrophysics, cosmology, condensed matter/atomic physics and particle physics. These programs attract about 500 theorists from around the world each year. In addition, the INT faculty performs research on a similarly broad range of topics.

**Technical Facilities:**
The facility is an infrastructure center for designing and building complicated experiments that operate in a variety of venues. A precision machine shop and modern electronics shop exist for preparation of major components of collaborative off-site experiments (see website for more details).

The accelerator part of the facility is an FN tandem Van de Graaff that can also be operated with a terminal ion source for low energy helium or hydrogen isotope beams. Energies from 100 keV to 5 MeV with currents of tens of µA are available for those isotopes. Operating as a tandem, the usual range of ion beams with terminal voltage up to 9 MV are available. A $^8$B radioactive beam of 10 ions/second has been developed. A table is available on the website.

CENPA is not a DOE user facility, but outsiders can run experiments collaboratively and/or by various arrangements. Experimental proposals are evaluated by the Director and Associate Director in consultation with the faculty.

Besides the students and postdocs, we have technical staff (engineers and techs) of 11.5 and administrative staff of 2. In summer several Research Experience for Undergraduates (REU) students work at CENPA. REU is an NSF-sponsored program.

**Scientific Mission and Research Programs:**
CENPA physicists played a major role in the SNO experiment that resolved the solar neutrino problem, showing it was caused by neutrino oscillations and mass. The KATRIN project is a large experiment to measure the neutrino’s mass. The MAJORANA and SNO+ projects search for neutrinoless double beta decay, which would be a signal that neutrinos and antineutrinos are the same particle. CENPA physicists are spearheading two high-precision measurements involving muons. The New (g-2) Experiment at Fermilab will sensitively test the Standard Model and the MuSun experiment at the Paul Scherrer Institute will determine a central parameter in the theory of fundamental astrophysics processes. CENPA has developed the most
CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY

Southwest United States

Cyclotron Institute
Texas A&M University
College Station, TX 77843
Telephone: 979 845-1411
Facsimile: 979 845-1899
E-mail: r-tribble@tamu.edu

University Facility (Department of Energy University Laboratory)
Construction: Department of Energy Office of Science for Nuclear Physics
Operations: Department of Energy Office of Science for Nuclear Physics

Dr. Elsa Murano, President Texas A&M University

Head of the facility:
Robert E. Tribble

Scientific Mission and Research Programs:
The Cyclotron Institute is jointly operated by the U.S. Department of Energy and the State of Texas to carry out a program of basic research in nuclear science. Institute programs include measurements of reaction rates for nuclear astrophysics, studies of heavy-ion reactions at low and intermediate energies, determination of the properties of giant resonances in nuclei and β-decay studies of fundamental weak interaction parameters. In addition, the Institute provides beam time for government and industrial laboratories to test electronics components for space satellites.

Technical facilities:
The centerpiece of the Institute is a K500 superconducting cyclotron, from which first beams were extracted in 1988. An upgrade project, described below, is nearly complete that will produce accelerated radioactive ion beams. The first step in the upgrade has been to re-commission the K150 cyclotron. The facility layout in the figure below shows the laboratory as it is now configured.

As of mid 2009, the beam lines that couple the K150 cyclotron to experimental areas were in place and experiments with both machines were being carried out.

Facility:
The Cyclotron Institute operates a low to medium energy superconducting cyclotron. Beginning in the fall of 2009, the K150 cyclotron also became operational for experiments. Both cyclotrons are injected by ECR ion sources. The first accelerated radioactive ion beams are planned for 2014.

Facility parameters:
The figure directly below shows the range of beams and beam energies which have been extracted from the K500 cyclotron. Over 55 different beam species have been run at varying energies. The maximum energy run to date is 70 MeV/A for light ions. U beams have been run at 12 MeV/A. Intensities up to 1 particle µamp have been achieved for extracted heavy-ion beams. In the table below, the beams are summarized by groups.
<table>
<thead>
<tr>
<th>Beams</th>
<th>Energy range (MeV/u)</th>
<th>Max. Intensities (pnA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>53 – 70</td>
<td>1000</td>
</tr>
<tr>
<td>α</td>
<td>12 – 30, 53 – 70</td>
<td>1000</td>
</tr>
<tr>
<td>Li</td>
<td>4 – 70</td>
<td>400</td>
</tr>
<tr>
<td>Be, B, C, N, O</td>
<td>2 – 70</td>
<td>700</td>
</tr>
</tbody>
</table>

### Major experimental equipment:

<table>
<thead>
<tr>
<th>Device</th>
<th>Description</th>
<th>Parameters</th>
<th>Primary Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARS</td>
<td>Recoil Spectrometer</td>
<td>$\Delta\Omega = 9\text{msr; } K^* = 160$; $\Delta m/m = 300$</td>
<td>Secondary beam production</td>
</tr>
<tr>
<td>MDM</td>
<td>Magnetic spectrometer</td>
<td>$\Delta\Omega = 8\text{msr; } K^* = 400$; $\Delta E/E = 1/4500$</td>
<td>Elastic, inelastic and transfer reaction studies</td>
</tr>
<tr>
<td>NIMROD</td>
<td>Neutron and charged Particle detector</td>
<td>4ndetector for neutron and charged particle multiplicities</td>
<td>Heavy-ion reaction mechanism and equation of state studies</td>
</tr>
</tbody>
</table>

### User facility

No

### Program Advisory Committee/experiment proposals:

No

### Average number of users:

Over past couple of years, in-house users average approximately 45, external users (non SEE line) average approximately 150 and SEE-line users average approximately 75. Of the 150 external users, about 30% are from outside the US in a typical year.

### Percentage of users and facility use:

Approximately 6500 hours of beam time are provided each year by the K500 cyclotron. About 40% of this is used for SEE-line testing and the remaining 60% is used for basic research. Outside users (nearly always) collaborate with Institute faculty and staff. The K150 cyclotron provided about 3000 hours of beam time in 2012. This is expected to increase in the future.

### Outside users

In a typical year, nearly all of the users outside of the US come from Europe.

### User Group:

K500 CYCLOTRON + ECR

![Graph showing E/A (MeV/Nucleon) vs Atomic Mass Number]
Staff numbers:
(a) permanent staff – 55
(b) temporary staff – 32

Number of theoretical staff:
(a) permanent – 6 (three faculty)
(b) postdoctoral – 3
(c) graduate students – 4

Number of postdoctoral researchers: 14

Number of graduate students: 28

Number of non-resident graduate students: 0

Special student programs:
We operate a summer program for 12 undergraduate students as a National Science Foundation REU site for nuclear science.

Development plans: We have nearly completed an upgrade of the Institute to produce and re-accelerate radioactive beams. We have re-activated our K150 (88”) cyclotron and will use it to produce secondary beams. The secondaries will be stopped in ion-guide gas stoppers and transferred to a charge-breeding ECR source where highly-charged ions will be produced. Following the charge-breeding ECR source, the ions will be injected into the K500 cyclotron and accelerated. The figure above for stable beams gives the operating range for unstable beams.

The upgrade project has been funded by the Department of Energy, Texas A&M University and the R.A. Welch Foundation. Total funding available for the upgrade is $5 M. The Management Plan for the upgrade was approved in December, 2004 by the Department of Energy. The layout of the laboratory following the upgrade is shown in the figure below.
HOPE COLLEGE ION BEAM ANALYSIS LABORATORY (HIBAL)

Hope College, Holland, MI

c/o Graham Peaslee
Chemistry Department
Hope College
Holland, MI 49423

Telephone: 616-395-7117
Facsimile: 616-395-7118
Accelerator lab: 616-395-7519
E-mail: peaslee@hope.edu

University Laboratory

Construction: National Science Foundation – MRI#0319523
Operation: Hope College and individual PI grants

James Bultman, President

Head of the facility:
Graham F. Peaslee (PI)

Scientific Mission and Research Programs:
The Hope College Ion Beam Analysis Laboratory is a low-energy light ion facility that provides routine PIXE, µPIXE, and RBS measurements for a variety of research projects. Current research projects include PIXE analysis of metals in lake sediments, µPIXE analysis of sand grains for provenance studies, µPIXE and PIXE analysis of dinosaur bones and surrounding strata from a Wyoming dig site, RBS characterization of organometallic electrochemical films, RBS characterization of vapor deposited amorphous GaN and ScN films, and energy-loss measurements and coincident x-ray detection of protein electrophoresis gels. In addition to basic research, HIBAL serves as a training facility for the next generation of interdisciplinary scientists as our undergraduate researcher are taught the routine operation, maintenance, sample preparation, data acquisition and analysis skills required to perform the basic research described above. Occasionally some applied research for local companies is performed as well.

Technical facilities:
Characterization of the facility:
The accelerator is a 1.7 MV NEC tandem Pelletron with an Alphatross external ion source.

Provide a compact table of facility parameters:

<table>
<thead>
<tr>
<th>Beam type</th>
<th>Energy range</th>
<th>Intensity on target</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H+</td>
<td>0.5 – 3.4 MeV</td>
<td>&lt;500 nA</td>
</tr>
<tr>
<td>4He+ and 4He 2+</td>
<td>0.5 – 5.1 MeV</td>
<td>&lt;500 nA</td>
</tr>
</tbody>
</table>

Provide a compact table of facility’s major experimental instrumentation:

<table>
<thead>
<tr>
<th>Qty</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Analysis beamlines with scattering chambers</td>
</tr>
<tr>
<td>2</td>
<td>Si(Li) detectors</td>
</tr>
<tr>
<td>1</td>
<td>Electrostatic microprobe end-station (10 micron)</td>
</tr>
<tr>
<td>1</td>
<td>CAMAC-based FPGA acquisition system</td>
</tr>
<tr>
<td>Assorted</td>
<td>Surface barrier Si detectors and electronics</td>
</tr>
</tbody>
</table>

Nature of user facility:
No

Program Advisory Committee/ experiment proposals:
No

Number of users of the facility:
(The facility was installed less than 6 months ago)
To date we have had 6 faculty members as users and 11 undergraduates as users and 1 external user.

Percentage of users and percentage of facility use from inside the institution:
95% and 98%

Percentage of users of facility from national users:
0%

Percentage of users of facility from outside the country:
0%

Does a formal users group exist for your facility:
No

Number of (a) permanent staff and (b) temporary staff:
(a) 0.5 FTE technician
(b) 1.0 undergraduate student

Number of theoretical staff:
0

Number of post-doctoral researchers:
0

Number of graduate students:
0

Number of undergraduate students:
Approximately 8 users in any given semester. Approximately 12-16 users during the summer.

Special student programs:
Most of our research (>80%) involves undergraduate students directly. We do lots of local tours.

Future Plans:
The third beamline is still under construction.
We will add a new x-ray detector soon.
We will upgrade acquisition system for the microprobe
THE INSTITUTE FOR NUCLEAR THEORY

University of Washington
Physics/Astronomy Building
Box 351550
Seattle, WA 98195-1550
USA

Telephone: +1 206 685 3730
Facsimile: +1 206 685 3360
E-mail: vilett@uw.edu
URL: http://www.int.washington.edu

David B. Kaplan, Director
Telephone: +1 206 685 3546
E-mail: dbkaplan@uw.edu

Linda Vilett, Administrator
Telephone: +1 206 685 3958
E-mail: vilett@uw.edu

US Department of Energy, local funding (University of Washington), other grants.

Head of the facility:
Professor David B. Kaplan

Facility:
The INT hosts scientific visitor programs of four weeks or longer in duration, as well as shorter topical workshops lasting 2-5 days. Subjects of these meetings range over all of nuclear theory, broadly defined, often with interdisciplinary connections to other branches of physics. The INT also hosts summer schools and administers the National Nuclear Physics Summer School. The INT has a permanent research staff of four Senior Fellows, as well as a couple of five-year Fellows and a variable number of post-docs. An administrative staff helps with organization of INT visitor programs, with meeting the IT needs of visitors, and with maintaining the INT web page, on which INT seminars are archived.

Technical Facilities:
The INT is located within the Physics and Astronomy building at the University of Washington, and physically consists of over 20 desks for visitors, mostly two desks per office. Visitors have internet access and printing capability.

Rooms of various sizes are available for seminars, informal discussions and larger conferences.

National Advisory Committee (membership as of September 2013):
Gail McLaughlin (chair), John Arrington, Vincenzo Cirigliano, Thomas Cohen, Susan Gardner, Hans-Werner Hammer, Ulrich Heinz, Charles Horowitz, Daniel Phillips, and Sofia Quaglioni. Membership is typically nine people, with three rotating off each year. New members approved by the DOE.

Main Instrumentation for Nuclear Physics Experiments:
None

Main Fields of Nuclear Research:
Nuclear structure and dynamics, QCD and hadron physics, lattice field theory, relativistic heavy ion collisions, nuclear matter under extreme conditions, nuclear astrophysics, precision tests of physics beyond the Standard Model, and interdisciplinary connections to nuclear physics.
Main Fields of Other Research:
Related Areas: Particle physics, astrophysics, condensed matter physics, many-body atomic physics, mesoscopic physics, computer science.

Number of active users and their origin:
Approximately 400 users per year, from various international origins.

User group:
Users: approximately 400 per year. Accumulated email list includes over 2000 past visitors to the INT.

Number of a) permanent staff and b) temporary staff (including graduate students and postdoctoral researchers):
2013: Permanent scientific staff: 4, temporary scientific staff: 10; administrative staff: 5.

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
2013:
Permanent: one Director, three Senior Fellows; Temporary: two 5-year Fellows, 4 post-docs, 4 graduate students.

Number of graduate students resident at the facility:
Typically 35-60 graduate students participate in INT summer schools, when hosted. A few graduate students attend INT programs and workshops each year, usually with their thesis advisers.

Involvement of undergraduate students in research (approximate average number at a given time):
One.
Head of the facility:
C. Konrad Gelbke, Director, NSCL and FRIB

Scientific Mission and Research Programs:
The overall mission of the National Superconducting Cyclotron Laboratory (NSCL) is to provide forefront research opportunities with stable and rare isotope beams. A broad research program is made possible by the large range of primary and secondary (rare isotope) beams provided by the facility. The facility has produced over 870 rare isotope beams for experiments, and 65 new isotopes have been discovered at NSCL. The major research thrust is to determine the nature and properties of atomic nuclei, especially those near the limits of nuclear stability. Other major activities are related to nuclear properties that influence stellar evolution, explosive phenomena in the cosmos (e.g. supernovae and x-ray bursters), and the synthesis of the heavy elements; and research and development in accelerator and instrumention physics, including the development of superconducting radiofrequency cavities and design concepts for future accelerators for basic research and societal applications. In all activities an important part of the NSCL program is the training of the next generation of scientists.

Technical facilities:
The floor plan of NSCL’s technical facilities shows the two superconducting cyclotrons (K500 and K1200 on the left), the superconducting A1900 fragment separator and subsequent beam lines, the various experimental vaults, the gas stopping and low energy beam area, the LINAC-based ReAccelerator (ReA3) facility, the SRF (superconducting RF) R&D area, the cryoplant, and the shops and assembly areas.

Characterization of the facility:
Coupled superconducting cyclotrons, all stable ions, intense radioactive beams separated by physical means, beams stopped in and extracted from a gas cell for use at very low energies or reacceleration with a 3-6 MeV/u superconducting LINAC.

Facility Parameters:

<table>
<thead>
<tr>
<th>Particle</th>
<th>Energy [MeV/u]</th>
<th>Intensity [pnA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{16}\text{O})</td>
<td>150</td>
<td>175</td>
</tr>
<tr>
<td>(^{18}\text{O})</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>(^{20}\text{Ne})</td>
<td>170</td>
<td>80</td>
</tr>
<tr>
<td>(^{22}\text{Ne})</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>(^{22}\text{Ne})</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>(^{24}\text{Mg})</td>
<td>170</td>
<td>60</td>
</tr>
<tr>
<td>(^{36}\text{Ar})</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>(^{40}\text{Ar})</td>
<td>140</td>
<td>75</td>
</tr>
</tbody>
</table>
Over 870 rare isotope beams produced by fragmentation of the primary beams were used in experiments at NSCL during 2001-2013.

Major experimental instrumentation and its capabilities:

1. For production and separation of radioactive ion beams: A1900 fragment separator; RF Fragment Separator.

2. For charged-particle spectroscopy: S800 spectrograph, Sweeper Magnet.

3. For charged particle detection over large solid angle: High Resolution silicon strip detector Array (HiRA); Active Target Time Projection Chamber (AT-TPC).

4. For neutron detection: Modular Neutron Array and Large Multi-Institutional Scintillator Array (MoNA-LISA); Neutron Walls; Neutron Emission Ratio Observer (NERO); Low-Energy Neutron Detector Array (LEnda).

5. For gamma-ray detection: Segmented Germanium Array (SeGA); CsI Array (CAESAR); Summing NaI detector (SuN).

6. For beta-decay studies: Beta Counting System.

7. For low energy beam studies: Low Energy Beam and Ion Trap (LEBiT); Beam Cooler and Laser Spectroscopy (BECOLA) facility; Single Ion Penning Trap (SIPT) mass spectrometer; Minitrap.

8. For lifetime measurements: Triple plunger for exotic beams (TRIPLEX).

9. Other major experimental equipment that has been hosted by NSCL: Gamma-ray energy tracking array (GREtina); Array for Nuclear Astrophysics Studies with Exotic Nuclei (ANASEN); Versatile Array of Neutron Detectors at Low Energy (VANDLE).
Nature of user facility:
User facility funded by the U.S. National Science Foundation.

Program Advisory Committee/experiment proposals:
Yes

Number of actual, active users of the facility in a given year:
250

Percentage of users, and percentage of facility use that come from inside the institution:
16% of users come from inside the institution. Most of the facility usage is for mixed (inside and outside) user experiments (87% from 2008-2013). 8.3% of the facility usage from 2008-2013 was for inside-only experiments.

Percentage of users and percentage of facility use from national users:
57% and 85%. [Note: Since most experiments involve international collaborations, we define facility use as the percentage of experiments from 2008-2013 with US spokespersons.]

Percentage of users and percentage of facility use from outside the country where your facility is located:
43% and 15%. [Note: Since most experiments involve international collaborations, we define facility use as the percentage of experiments from 2008-2013 with non-US spokespersons.]

Fraction of the international users from outside geographical region:
100%.

User Group:
1342.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 528 total laboratory staff
b) 123 scientists on staff with doctoral degrees

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
23 total (8 faculty, 6 postdoctoral, 9 students)

Number of postdoctoral researchers:
25

Number of graduate students resident at the facility:
60

Number of non-resident graduate students with thesis work primarily done at the facility:
10

Involvement of undergraduate students in research (approximate average number per year):
Approximately 30

Special student programs:
Undergrads:
REU: Research Experience for Undergraduates
CEU: Conference Experiments for Undergraduates
Professional Assistant Program

High school and others:
PAN: Physics of the Atomic Nuclei
Mini-PAN: One-day version of PAN
MST: Mathematics, Science, and Technology camp
Catch-a-Cosmic-Ray event
NSCL Open House (more than 900 visitors)

Future Plans:
Upon completion (by 2022) of the DOE Facility for Rare Isotope Beams (FRIB), the laboratory will transition to experiments with beams this forefront facility. To enable the best science now and when FRIB is complete, the laboratory emphasizes construction of state-of-the-art instrumentation in nuclear and accelerator physics. Several new devices were commissioned in the past year including a gas cell from which stopped rare isotope beams can be extracted for experimentation at very low energy or for reacceleration, an EBIT charge breeder for transport to the reaccelerator, the ReAccelerator (ReA), the Low Energy Beam and Ion Trap (LEBIT) facility, the BEam Cooler and Laser spectroscopy (BECOLA) facility, the SuN detector, and the full scale AT-TPC detector. Projects in progress include the cyclotron gas stopper.
Head of the facility: Dr. Muhammad Arif

Scientific Mission and Research Programs:
The NIST Fundamental Physics Neutron Facility provides a location for internal and external users to conduct both fundamental and applied physics experiments with thermal, cold, and ultracold neutrons. The research program includes studies of the weak interaction, neutron instrumentation, neutron interferometry, neutron imaging, neutron fluence measurements and dosimetry, and applications to homeland security. Past and current experiments in weak interaction physics include measurements of the neutron lifetime, a search for time reversal violation in polarized neutron decay, study of nucleon-nucleon interactions via parity-violating spin-rotation of polarized neutrons, a search for the radiative decay mode of the neutron, and precision measurements of neutron scattering lengths. Instrumentation development is focused on the polarized $^3$He-based neutron spin filters for neutron scattering and fundamental neutron physics. The neutron imaging program includes studies of fuel cells.

Technical Facilities:
The layout of the NIST Center for Neutron Research (NCNR) cold neutron guide halls is shown below. The NCNR is operated by the Materials Science and Engineering Laboratory of NIST. The Neutron Physics Group operates the NG-6 beam line for fundamental physics, along with the NG-6A, NG-6M, and NG-6U monochromatic beam lines, the NG-7 and NG-7A Neutron Interferometer and Optics Facility, and two thermal neutron stations (not shown). The NG-C high flux beam is built but not yet commissioned.
Characterization of the Facility:

Thermal and cold neutron beam lines at a research reactor

Facility Parameters:

**NG-6** cold, polychromatic beam line:
neutron fluence rate (no filters) = $2.3 \times 10^9$ cm$^{-2}$ s$^{-1}$
6 cm diameter beam

**NG-C** cold, polychromatic beam line:
ballistic guide
projected neutron fluence rate = $1 \times 10^{10}$ cm$^{-2}$ s$^{-1}$
guide size = 11 cm x 11 cm beam

**NG-6M** monochromatic beam line:
wavelength = 0.496 nm
typical fluence rate = $6.5 \times 10^5$ cm$^{-2}$ s$^{-1}$
pyrolytic graphite crystal size = 5.1 cm by 5.1 cm

**NG-6A** monochromatic beam line:
wavelength = 0.381 nm
typical available fluence rate = $8.3 \times 10^5$ cm$^{-2}$ s$^{-1}$
Si<111> crystal size = 2.7 cm x 5.0 cm

**NG-6U** monochromatic beam line:
wavelength = 0.89 nm
capture fluence rate = $4.7 \times 10^6$ cm$^{-2}$ s$^{-1}$
potassium-intercalated graphite monochromatic
beam size = 6 cm x 6 cm

**NG-7** Neutron Interferometer and Optics Facility:
pyrolytic graphite crystal
wavelengths - 0.2 nm - 0.48 nm
fluence rate - $2 \times 10^5$ cm$^{-2}$ s$^{-1}$
beam size = 2 mm x 8 mm
phase stability - 0.25 degrees/day
contrast - 90%

**NG-7A** NIOFa monochromatic beam
pyrolytic graphite crystal
wavelength = 0.440 nm
fluence rate = $3.6 \times 10^6$ cm$^{-2}$ s$^{-1}$
beam size = 4.0 cm by 5.0 cm

Major experimental instrumentation and its capabilities:
In addition to the neutron beam lines, the facility has apparatus for spin-exchange and metastability-exchange optical pumping of $^3$He neutron spin filters. There is also a thermal beam for neutron imaging.

Nature of user facility:
The neutron beam lines are considered to be a user facility by the NIST Center for Neutron Research as well as the Neutron Interactions and Dosimetry group.

Program Advisory Committee/experiment proposals:
Yes, there is a Beam Time Allocation Committee for the NG-6 and -C neutron beam lines.

Number of actual, active users of the facility in a given year:
We estimate that about 30 people per year have made use of our facilities in the last year.

Percentage of users, and percentage of facility use that come from inside the institution:
Percentage of users from inside the institution - zero (we define "users" to be from the outside)
Percentage of facility use from inside the institution - 50%

Percentage of users and percentage of facility use from national users:
80% (users); 40% (facility use)

Percentage of users and percentage of facility use from outside the country where your facility is located:
20% (users); 10% (facility use)

Fraction of international users outside of geographical region:
100%

User Group:
No

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
Permanent staff = 12; Temporary staff = 10
Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
0

Number of postdoctoral researchers:
3

Number of graduate students resident at the facility:
6

Number of non-resident graduate students with thesis work primarily done at the facility:
2

Involvement of undergraduate students in research (approximate average number per year):
3 (summer); 1 (academic year)

Special student programs:
Summer Undergraduate Research Program, sponsored by NIST, the NSF, and the students' institutions. Organizer for the 3rd “Summer School on Fundamental Neutron Physics” Vancouver, BC Aug. 6-17 2012 as part of the 2012 TRIUMF Summer Institute.
NUCLEAR SCIENCE LABORATORY (NSL)
UNIVERSITY OF NOTRE DAME
Institute for Structure and Nuclear Astrophysics (ISNAP)

North America

ISNAP or Nuclear Science Laboratory
Department of Physics
124 Nieuwland Science Hall
University of Notre Dame
Notre Dame, IN 46556

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University Institute

Construction: University of Notre Dame
Operation: National Science Foundation

Rev. John Jenkins, CSC, President

Head of the facility:
Prof. Michael Wiescher

Scientific Mission and Research Programs:
The NSL group’s research spans low energy nuclear physics with a focus on nuclear astrophysics, nuclear structure physics and nuclear physics applications. The nuclear astrophysics program has centered on the study of low energy nuclear reactions in stellar hydrogen, helium, and carbon burning. This is of particular importance for the understanding of nucleosynthesis in early stars, the origin of seed materials in explosive stellar environments and the source of neutrinos in our sun and other main sequence stars. The focus is on the study of key reactions for neutrino and neutron production in quiescent and explosive stellar environments which are being investigated using in-beam gamma and particle measurement techniques. These are complemented by inverse kinematics techniques that utilize the recently constructed St. GEORGE recoil separator.

This program is complemented by transfer reaction measurements using the TwinSOL facility as a high acceptance momentum separator to determine decay branchings for sub-threshold states or spectroscopic information on resonance contributions that cannot be measured directly.

New theoretical tools have been developed for deriving reliable stellar reaction rates from the experimental data and for investigating the impact of the nuclear reactions on nucleosynthesis, energy production and time scale of dynamic stellar environments.

Studies of critical nuclear structure parameters (e.g., masses, deformation, and incompressibility) have been performed to extract information on critical input for understanding the nucleosynthesis aspects of core collapse supernovae associated with the p- and r-process and the origin of long-lived galactic γ-ray sources.

The program in Accelerator Mass Spectrometry is focused on questions of long-lived radioactivities like $\text{^{36}Cl}$, $\text{^{44}Ti}$, $\text{^{60}Fe}$, and $\text{^{93}Zr}$ of nucleosynthesis origin, but branches out into applications of
relevance for the analysis of environmental and geophysical samples.

Beyond interests in nuclear astrophysics, the nuclear structure effort has focused on the investigation of collective modes and on novel modes of quantal rotation using techniques of $\gamma$-ray spectroscopy.

Strong efforts have been made to develop a program in nuclear physics and accelerator applications, often in collaboration with other university groups and institutions. This includes the development of AMS techniques using new long-lived isotopes as well as the application of PIXE and X-Ray Fluorescence (XRF) as analytical tools on archaeological, forensic, and biological samples.

**Technical facilities:**

The centerpiece of the Nuclear Science Laboratory (NSL) is the model FN Tandem Pelletron Accelerator, which is capable of reaching acceleration voltages in excess of 11.5 MegaVolts. The FN Tandem is used to accelerate a wide variety of ion beams to energies that range from a few MeV to 100 MeV. Most of these ion beams are produced by a Multi Sputter Ion Source (SNICS), with helium beams being produced using a Duoplasmatron Source (HIS). In addition to the continuous, or DC, beams available from these sources, experimenters may elect to bunch and pulse the beams. The buncher/pulser system is capable of producing beam pulses of about 1.5 nsec width, separated by 100 nsec (or by some multiple of 100 nsec using the pulse selector).

The FN tandem is the driver for the TwinSOL radioactive beam facility, which provides high intensity light radioactive ion-beams for nuclear structure and reaction studies. Beams of $^6\text{He}$, $^7\text{Be}$, $^8\text{Li}$, $^8\text{B}$, $^{10}\text{Be}$, $^{12}\text{B}$, $^{12}\text{N}$, and $^{18}\text{Ne}$ have been used in experiments. Maximum intensities from $10^5$ to $10^7$ s$^{-1}$, depending on the beam, are observed. Beams such as $^{11,14}\text{C}$, $^{15}\text{O}$, and $^{17,18}\text{F}$ have been developed with a similar range of intensities but have not been used in experiments to date.

The FN tandem also serves as the core for the AMS program of the NSL. The separation is improved by an additional velocity filter positioned after the second analyzing magnet in the AMS beam-line.

The gas-filled Browne-Buechner Spectrometer serves now as last station for isobar separation.

In addition to the FN Tandem accelerator, the laboratory also operates a single ended model 5U Pelletron accelerator, which was installed in 2012. This accelerator has a maximum accelerating voltage of 5 MegaVolts and provides high intensity positive charged low-mass beams in different charge states from a Nanogan ECR used mounted in the terminal, for experimental nuclear astrophysics applications.

The 5U Pelletron serves three beam-lines, two are equipped with high beam power target stations, one a solid beam-stop target for radiative capture experiments, and one a recirculating gas target system, which can be operated both in the extended as well as jet target mode. These two beam lines will be primarily used for intense light ion proton and alpha beams, while a third beam line is dedicated to heavy ion beam experiments with the recoil separator St. GEORGE.

St. GEORGE is a state of the art recoil separator for separating heavy recoil reaction products from low energy inverse kinematics experiments. The device is designed and dedicated to the studies of critical nuclear reactions in stellar helium burning. The reactions take place in a high density helium jet gas target HIPPO, with the heavy ion beam being delivered by the 5U accelerator. St. GEORGE consists of 14 quadrupole and six dipole magnets to ensure proper charge separation and mass separation between primary beam particles and reaction recoils. The main separation is based on a velocity filter positioned after the first separation units. St. GEORGE has a calculated rejection power of $10^{15}$ and a predicted mass resolving power of 100.
The ICeBall conversion electron array has been recently moved to the NSL and recommissioned to allow measurements of conversion electrons in coincidence with the pulsed beam and gamma rays introducing a new capability to measure multipolarities of transitions with the laboratory.

**Characterization of the facility:**
Low-energy accelerators with light to medium ions with high intensity.

**Brief and compact table with the facility's major experimental instrumentation and its capabilities:**
Listed above

**Nature of user facility:**
Officially we are not a user facility but we have a large number of users from all over the world, more than 60% of beam-time at the FN tandem is allocated for external user groups.

**Program Advisory Committee/experiment proposals**
The laboratory personnel meet once a week and make decisions on proposed experiments. The proposers typically give a brief 10-15 presentation to discuss why the experiment needs to be done and the associated technical requirements. The group then decides if there are competitive proposals, if the experiment is doable, and if the experiment is interesting. Then we attempt to find the best solution with regards to the schedule and competing resources.

**Number of actual, active users of the facility in a given year:**
50 approximately in a given year

(foreign countries, US Universities/Colleges, US National Laboratories, and some industrial Laboratories)

**Percentage of users, and percentage of facility use that come from inside the institution:**
There are two major inside users;
Radiation Laboratory Personnel (DOE funded laboratory on the campus of Notre Dame) and individual scientists from the Physics Dept. here at Notre Dame.

**Percentage of users and percentage of facility use from national users:**
50%

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
50%
Fraction of the international users from outside geographical region:
Middle East (Armenia, Israel, Turkey)
Asia (China, India, Japan)
Europe (Austria, Bulgaria, France, Germany, Hungary, Italy, UK)
South and Central America (Brazil, Mexico)
North America (Canada)

User Group:
No

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) laboratory staff - 7
b) scientist staff - 5

Number of postdoctoral researchers:
7

Number of graduate students resident at the facility
30

Number of non-resident graduate students with thesis work primarily done at the facility:
5

Involvement of undergraduate students in research (approximate average number per year):
15

Special student programs:
Research Experiences for Undergraduates (REU – summer program)
Research Experiences for Teachers (RET – summer program for High School Teachers)
Local High School students doing projects with faculty (academic year)
Quarknet network of High School Teachers (year round + special programs in the summer)

Future Plans:
Development of an underground accelerator laboratory DIANA (Dual Ion beam Accelerator for Nuclear Astrophysics), for background free measurements of low energy charged particle cross sections. The facility will be located at the 4850ft level of the Sanford Underground Research Facility in Lead, South Dakota. Presently a small 1megaVolt accelerator is being prepared and tested for a DIANA demonstrator pilot program.
The Pacific Northwest National Laboratory (PNNL) is a U.S. Department of Energy (DOE) multi-program National Laboratory that creates new knowledge and solutions that address national challenges in science, national security, environmental quality, and energy resources. PNNL’s 4700 staff conduct a broad research agenda (approximately $1.1B in 2012) in 180,000 square meters of facilities, most of which are located in Richland, Washington. Additional facilities are operated in Washington, DC, Seattle, WA, Sequim, WA, and Portland, OR. PNNL has staff expertise and capabilities that have direct application to nuclear and high-energy physics programs. The main sources of funding for PNNL are from the U.S. Departments of Energy, Homeland Security, and Defense.

For example, in the area of $^{76}$Ge double-beta decay, starting in the 1980s, PNNL researchers produced the technology for one of the two worldwide $^{76}$Ge experiments, which led to publishing the half-life of the two-neutrino mode of decay in 1990. Since that time, PNNL-led developments in the chemistry of ultra-pure materials, development and testing of signal analysis methods, and deployment of ultra-low-level, radiopurity screening technology via radiometric analysis and mass spectrometry have resulted in the successful operation of the International Germanium Experiment (IGEX). PNNL staff organized a collaboration of scientists to pursue the challenge of determining the mass and character of the neutrino, qualities indicated by the measurement of the oscillation of neutrinos in solar, atmospheric, and reactor experiments. This Majorana Demonstrator experiment (http://www.npl.washington.edu/majorana/) is envisioned ultimately to become a tonne-scale, $^{76}$Ge double-beta decay experiment, with sensitivity to an effective Majorana mass of the electron neutrino below 45 meV. Majorana will require the use and extension of the capabilities of PNNL and other labs in materials science, analytical chemistry, and surface science (for the exploration of more germanium-efficient electrical contacts). These developments have also aided several ongoing dark matter experiments.

An Underground Sciences Laboratory facility located at PNNL, completed in 2010, provides a shielded environment of about 6000 square feet at about 35 meters-water-equivalent for continued development of the research program in ultra-low background physics for national security and basic physics applications, including Majorana and dark matter experiments. This underground facility replaced a low-background detection laboratory, a laboratory for low-background materials growth and assay, plus the use of offsite underground facilities.

PNNL’s Environmental Molecular Science Laboratory (http://emsl.pnl.gov) is a national DOE user facility, with state-of-the-art equipment for advanced materials and surface science, such as that needed for detector development for the Majorana Demonstrator and dark matter experiments and for other physics research. PNNL’s Category II Radiochemical Processing Facility includes capabilities in trace and high-level radioactive chemical separations and analyses, which are needed to perform extremely hot chemical
separations needed for neutrino sources and neutrino, magnetic-moment experiments.

PNNL’s growing pool of about 50 nuclear and high-energy physicists work with a much larger team of nuclear and materials scientists on large national security research as well as pure physics experiments such as the MAJORANA DEMONSTRATOR experiment. Postdoctoral fellows and graduate students from a number of universities work at PNNL on basic and applied physics projects. Undergraduate students participate in research and development work under DOE and laboratory summer programs.

Technical Facilities at PNNL
- Double-beta decay and dark matter detection development laboratory
- Low-background detection and materials assay laboratories
- Environmental Molecular Sciences Laboratory (DOE User Facility)
- Underground Sciences Laboratory

Environmental Molecular Sciences Laboratory at PNNL

PNNL Underground Science Laboratory
RELATIVISTIC HEAVY ION COLLIDER (RHIC)  
BROOKHAVEN NATIONAL LABORATORY (BNL)

P.O. Box 5000  
Upton, NY 11973, U.S.A.

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Dr. Doon Gibbs, Director  
Dr. Berndt Mueller, Associate Director, Nuclear and Particle Physics

BNL is managed by Brookhaven Science Associates for the  
U. S. Department of Energy Office of Science, Division of Nuclear Physics

Heads of RHIC-Related Departments:
Collider-Accelerator Department Chair: Dr. Thomas Roser  
Physics Department Chair: Dr. Laurence Littenberg

Scientific Mission and Research Programs:
Brookhaven National Laboratory is a multi-program  
U.S. Department of Energy laboratory with scientific programs in Particle Physics; Nuclear Physics; Basic Energy Sciences; Life Sciences; and Applied Sciences. A guide to the laboratory can be found on the web site www.bnl.gov.

The principal facility for Nuclear and Particle Physics (NPP) is the Relativistic Heavy Ion Collider (RHIC), which can collide ions as heavy as uranium at beam energies up to 100 GeV/nucleon and polarized protons up to 250 GeV. Two detectors, STAR (large solid-angle tracking with time projection chamber, electromagnetic calorimetry, and particle identification via time-of-flight in a solenoidal magnetic field) and PHENIX (magnetic spectrometer with many high-rate detector systems to measure hadrons, electrons, muons, and photons), are used to study reaction products from ion-ion or p-p collisions.

The primary scientific mission of RHIC is to explore the unique quantum many-body phenomena exhibited by matter governed by QCD, under extreme conditions analogous to those attained in the first microseconds of the universe following the Big Bang. A secondary mission is to quantify the contributions of gluons and sea quarks and antiquarks to the overall spin of a proton. Major discoveries to date include the transition at very high temperatures from ordinary nuclear matter to quark-gluon matter that behaves as a nearly viscous-free liquid, and observation that gluon spin orientation preferences do not dominate the proton spin.

The layout of RHIC on the BNL site and an illustration of its two detectors are shown in Figure 1. Table 1 summarizes the collider’s capabilities achieved to date.
Technical facilities:

Characterization of the facility:
relativistic heavy ion collider; polarized proton collider

Facility Parameters:
RHIC Facility:

Exemplary tables on RHIC performance:

Table 1: Achieved beam parameters and luminosities for the highest-energy collisions of Au+Au, Cu+Cu, d+Au, and p+p. RHIC has also operated extensively at lower energies
Brief and compact table with the facility's major experimental instrumentation and its capabilities:

RHIC Facility:
The instrumentation at RHIC consists of two collider detectors designed to provide complementary capabilities for measurements of high energy collisions of heavy nuclei and of spin-polarized protons. Each detector occupies one of the six beam-crossing regions in the RHIC ring.

PHENIX Detector – magnetic spectrometer with many detector systems for measurement of hadrons, electrons, muons, and photons

STAR Detector – Large solid-angle tracking with time projection chamber, followed by electromagnetic calorimetry, in a solenoidal magnetic field.

Nature of user facility:
DOE Designated National User Facility

Number of actual, active users of the facility in a given year:
RHIC has been designated as a User Facility by the U.S. Department of Energy and has a Program Advisory Committee (www.bnl.gov/npp/pac.asp). At present there are 958 users registered in the Users’ Office. Of these, 10% are BNL staff; 55% are from other U.S. institutions; and 45% from outside the U.S. Of the non-U.S. users, 54% are from Asia; 40% from Europe; 3% from South America; 1% from Africa; and 2% from North America. The RHIC/AGS Users’ Group (www.rhicuec.org) also includes users from the NASA Space Radiation Laboratory, a facility that principally makes use of one of the RHIC injectors to study the effects of heavy ion beams on biological materials.

User Group:
A formal users group exists. Its membership includes all guests involved in research at the RHIC complex including AGS, ATF, Tandem, and NSRL accelerators. Current membership is 1437.

Number of a) total RHIC facility staff (all categories) b) Scientists on RHIC staff with doctoral degree:
a) Total staff 422
b) Staff with doctoral degrees:
   i) Permanent 100
   ii) Temporary and postdoctoral 36

Number of theoretical staff employed at the facility:
a. Permanent Staff: 7
b. Temporary and Postdoctoral: 10

Number of postdoctoral researchers: 15

Number of graduate students resident at the facility:
a. Permanent Staff: 7
b. Temporary and Postdoctoral: 10

Number of non-resident graduate students with thesis work primarily done at the facility: 119

Involvement of undergraduate students in research (approximate average number per year):
Undergraduate and summer students (physics & engineering): ~ 60

**Future Plans:**

Future RHIC runs will utilize the recent eightfold enhanced luminosity and new detector microvertex capabilities to explore the transport properties of heavy quarks in the quark-gluon plasma. They will also test recent theoretical advances in understanding parton transverse motion and spin preferences in transversely polarized protons.

After the installation of electron cooling (planned for 2017), RHIC will search for evidence of a critical point in the thermodynamic phase diagram of QCD matter. After additional detector upgrades, plans call for a final set of runs with gold nuclei and protons to make precise measurements of parton energy loss, jet modification, and Upsilon production in hot QCD matter.

Major goals in accelerator R&D include development of high-current energy recovery linacs and a proof of principle demonstration of coherent electron cooling.

In the longer term, BNL proposes to add a 10 GeV polarized electron beam to the facility, providing high-energy, high-luminosity electron-nucleus and polarized electron-proton collisions. This eRHIC project will extend deep inelastic scattering measurements of the partonic structure of nucleons and nuclei into the region where the constituents are completely dominated by self-interacting gluons. This extended reach will enable tests of QCD and predicted universal behavior in cold matter characterized by very high, possibly saturated, densities of gluons. It will also facilitate three-dimensional visualizations of internal structure and mapping of proton spin contributions in this gluon-dominated domain.
Sanford Underground Research Facility

**Name of institution and/or facility(s):**
Sanford Underground Research Facility (SURF)

**Geographic location:**
Lead, South Dakota (Former Homestake Mine)

**Full address (regular and e-mail addresses; as well as telephone, facsimile #'s, etc.):**
630 E. Summit St. Lead, SD 57754
Main phone: (605) 722-8650
Sanfordlab.org

(Legal) form/status of the institution/facility (e.g. university institute; DoE laboratory; limited liability company under, for example, French/British/German/Japanese.... law):
State-owned and operated Research Facility, managed and overseen for the US Department of Energy, Office of High Energy Physics, by Lawrence Berkeley National Laboratory.

Main source of funding for a) construction, b) operation and c) other (if applicable):
DOE- HEP (operations, maintenance, science support)
State of South Dakota (facility improvement, Education and Outreach)

**Head of the institution:**
The LBNL Office overseeing SURF is lead by
Kevin Lesko, Head of Sanford Underground Research Facility,
Gil Gilchriese, deputy Head, Physics Division, LBNL,
KTLesko@lbl.gov, MGGilchriese@lbl.gov

**Head(s) of the facility(s):**
Mike Headley, Sanford Laboratory Director,
MHeadley@sanfordlab.org

**In a brief abstract (5 – 10 lines) describe the scientific mission and, broadly, the main current and future research programs of the institution/facility:**
SURF hosts physics and other research that benefits from well-shielded and deep underground facilities including:

- Neutrino research
  - Long Baseline Neutrinos Experiments
  - Neutrinoless Double Beta Decay Searches
- Dark Matter Searches
- Nuclear Astrophysics
Technical facilities: please provide one (for smaller facilities) or two (for larger facilities) figures and/or photos providing the technical layout of the facility and its instrumentation, and a visual overview (could be a photo).


Several well-furnished underground research laboratories at 4300mwe shielding (4850 feet below ground). Laboratories provide cleanrooms (CR classes 2000 down to 100), utilities, HVAC, access and professional support staff including environment, health and safety, engineering, experimental / scientific support staff. Low background radioassay (gamma-ray counting) facilities are available.

**4850L Sanford Laboratory**

Briefly characterize the facility (e.g. low-energy cyclotron with light-ion beams; relativistic heavy ion collider; rare-isotope beam facility; heavy-ion linac/synchrotron; pulsed electron linear accelerator, cw electron beam facility; back-scattered photon facility, deep-underground science facility, etc.):

Research facilities with ultra-low background environment including $10^7$ reduction in cosmic rays, very low levels of U and Th in the field rock, reduced activity concrete and assayed construction materials.

Provide a compact (exemplary) table of facility parameters (e.g. beam species, intensities, range of energies, special properties, background levels)

Two primary underground research campuses, with additional spaces available for R&D and smaller scale experiments. Significant surface facilities are available for engineering, prototyping and assembly activity.

If appropriate, provide a brief and compact table with the facility's major experimental instrumentation and its capabilities:
Low Background Counting and Assay capabilities
8m diameter water shielding tank
Class 2000 or better clean rooms, capable of clean rooms down to class ~100

**Is the facility considered to be a user facility (officially and by whom; unofficially?).**
**With user facility is meant a facility with users from other institutions or laboratories:**
SURF is a research facility, funded by the US DOE HEP, managed and administered by LBNL. It hosts experiments funded in the US by DOE and NSF with significant international participation. Additional biology, geology and engineering efforts are conducted in the facility.

**Does the facility have a Program Advisory Committee or the equivalent, adjudicating proposals for experiments?**
Not currently. PAC existed in the past with National Science Foundation support. Needs for a PAC will be assessed as the current round of experiments advances to completion and in consultation with funding agencies.

**Number of actual, active users of the facility in a given year (an average over the last few years, or just the last year if the facility is new). Please indicate how the number is derived):**
Three principal physics collaborations, membership ~ 200. 20 ancillary experiments including biology, geology, and engineering efforts totalling ~50 members. Long Baseline Neutrinos Experiment advancing to preliminary design stage will add ~800 additional users. Generation 2 Dark Matter (LZ) will add ~150 members to the users total.

**Percentage of users, and percentage of facility use (these numbers may differ) that come from inside the institution (if no statistics exist, please give an estimate but indicate this as such):**
99% of the users are from outside SURF

**Percentage of users and percentage of facility use from national users:**
Majorana Demonstrator and LUX are international collaborations with ~90% from within the US.

**Percentage of users and percentage of facility use from outside the country where the facility is located:**
Majorana Demonstrator and LUX are international collaborations with ~10 to 15% from outside the US.

**What fraction of the international users is from outside the geographical region of the facility (i.e. Asia; Australia & New Zealand; North-America; South-America; Africa; Europe):**
Europe, Canada, Japan provide most of the international users currently. LBNE and LZ will add significant additional users from Europe (UK, Italy, Germany) but also from Brazil, India
Does a formal users group with statues and an executive exist for the facility(s) and what is the number of registered members (in general this may be quite different from the number of actual users in a given year):
A users associate (DURA) with ~ 600 members

Number of a) permanent staff, as scientific, technical, and administrative staff, employed by the facility and b) temporary staff (including graduate students and postdoctoral researchers on the facility’s payroll):
85 staff supported by DOE, additional staff supported by the state of South Dakota.

Number of theoretical staff employed at the facility: permanent; postdoctoral; and graduate students:
There are no theory positions supported by SURF funding. South Dakota supports a successful summer theory program in conjunction with SURF.

Number of postdoctoral researchers employed by the facility and separately the number of those seconded to the facility by other institutions or laboratories:
N/A

Number of graduate students resident at the facility (for more than 80% of their time):
2 SURF staff are graduate students, collaborations support ~ 50 graduate students conducting research at SURF as part of existing experiments. 5 to 10 residents at any given time.

Number of non-resident graduate students with thesis work primarily done at the facility:
See above

Involvement of undergraduate students in research (approximate average number at a given time):
~10 to 20 undergraduates, primarily in the summer.

Special student programs, e.g. summer schools, student lecture series, student laboratories, etc. (for high school, undergraduate, and graduate students):
Davis-Bahcall Scholarship program offered by South Dakota

Describe any plans that exist and their present status for future developments at the facility (facility upgrades; expansions of and new construction for the existing facility, major instrumentation additions, etc.):
LBNE would create major new facilities at SURF. LBNE is developing their preliminary design documentation at this time (October 2013). 3rd generation Dark Matter or 1-tonne neutrinoless double beta decay may require additional laboratory facilities underground. These needs will be assessed later in this decade.
SUPERCONDUCTING ACCELERATOR LABORATORY AT FLORIDA STATE UNIVERSITY

Tallahassee, Florida 32306 USA

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University Institute

U.S. National Science Foundation
Florida State University

University President Eric Barron

Head of the facility:
Prof. Samuel L. Tabor

Scientific Mission and Research Programs:
The mission of the laboratory is forefront research in nuclear physics and the education of graduate students. The major research programs are the study of nuclear reactions induced by radioactive beams, the structure of nuclei at high angular momentum, the structure of nuclei far from stability using both stable and radioactive beams, and reactions of importance in astrophysics.

Technical facilities:
Characterization of the facility:
9 MV tandem Van de Graaff accelerator injecting into a superconducting LINAC

Facility Parameters:

<table>
<thead>
<tr>
<th>Particle</th>
<th>enA</th>
<th>Max Energy (MeV)</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^1$H</td>
<td>1000</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>$^4$He</td>
<td>500</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>$^{6,7}$Li</td>
<td>300</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>$^{12}$C</td>
<td>1000</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>200</td>
<td>100</td>
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<td>$^{16}$O</td>
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<td></td>
</tr>
<tr>
<td>$^{28}$Si</td>
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<td>180</td>
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<td>$^{32}$S</td>
<td>1000</td>
<td>200</td>
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</tr>
<tr>
<td>$^{35}$Cl</td>
<td>800</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

Major experimental instrumentation and its capabilities:
1) In-flight radioactive beam line RESOLUT
2) Dedicated 14C ion source
3) Gamma detection array with digital electronics
4) Split-pole magnetic spectrometer coming
5) Scattering chambers, charged particle detectors
6) Neutron detector array

Nature of user facility:
Not a user facility

Program Advisory Committee/experiment proposals:
No PAC – collaborations can be discussed

Number of actual, active users of the facility in a given year:
Number of active users averaged over the last 5 years is 25 per year, including faculty, postdocs, and graduate students

Percentage of users, and percentage of facility use that come from inside the institution:
Estimated at 80% averaged over last 5 years

Percentage of users and percentage of facility use from national users:
10%

Percentage of users and percentage of facility use from outside the country where your facility is located:
10%

Fraction of the international users from outside geographical region:
100%

User Group:
No formal users' group

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 9 faculty and 7 technical staff
b) 1 postdoc and 2 scholar/scientists

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
a) 4 faculty
b) 1 postdoc

Number of postdoctoral researchers:
2

Number of graduate students resident at the facility:
21

Number of non-resident graduate students with thesis work primarily done at the facility:
2

Involvement of undergraduate students in research (approximate average number per year):
~9 per year

Special student programs:
Research Experience for Undergraduates, Summer Junior Fellows program for high school students

Future Plans:
Acquiring a wide acceptance split-pole magnetic spectrometer
Planning to add superconducting resonators to increase the maximum energy and mass of beams.
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY
(JEFFERSON LAB)

Newport News, Virginia; USA

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E-mail: bmck@JLab.org

Jefferson Lab is a user facility managed and operated by Jefferson Science Associates, LLC (JSA)
for the U.S. Department of Energy.

Department of Energy Office of Science for Nuclear Physics
Work for Others funded by the U.S. Department of Energy and the U.S. Department of Defense

Hugh Montgomery, Director

Heads of the facility:
Robert McKeown, Deputy Director for Science and Technology
Rolf Ent, Associate Director Experimental Nuclear Physics
Andrew Hutton, Associate Director Accelerator
George Neil, Associate Director Free Electron Laser

Scientific Mission and Research Programs:
The Department of Energy's Thomas Jefferson National Accelerator Facility, or Jefferson Lab (JLab), is a nuclear physics research laboratory built to explore the fundamental nature of confined states of quarks and gluons, including the nucleons that comprise the mass of the visible universe. The Continuous Electron Beam Accelerator Facility’s (CEBAF) high energy, (originally up to 6 GeV, with high current up to 200 μA), is at present undergoing an upgrade to double its energy to 12 GeV, with high current up to 90 μA. Its continuous wave electron beams and associated experimental equipment offer unique research capabilities to its international user community. Jefferson Lab is also a world-leader in the development of the superconducting radio-frequency (SRF) technology utilized for CEBAF. This technology is the basis for an increasing array of applications at JLab, other DOE labs, and in the international scientific community. At JLab, the advancement of SRF technology has enabled the 12 GeV Upgrade project. Additionally, it facilitated the development of JLab’s Free Electron Laser (FEL) and Energy Recovery Linac (ERL), key future state-of-the–art techniques to support Office of Science projects.

Characterization of the facility:
Jefferson Lab features a continuous wave recirculating electron accelerator providing beams from 0.05 up to 12 GeV, 100 picoamps to 90 microamps. CEBAF can provide beams simultaneously to three experimental halls (and a fourth hall as part of the upgrade), each with complementary experimental equipment. Jefferson Lab also houses the FEL, designed to provide 10 kW of laser light with picosecond pulse length, transform-limited bandwidth and diffraction-limited emittance.
Technical facilities:

Aerial photo of the Jefferson Lab accelerator site

CEBAF at 12 GeV

Upgrade is designed to build on existing facility; vast majority of accelerator and experimental equipment have continued use

20 cryomodules
Add 5 cryomodules

Add arc

CHL upgrade

New Hall
Upgrade arc magnets and supplies

Maintain capability to deliver lower pass beam energies: 2.2, 4.4, 6.6...

Add 5 cryomodules

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beam line
- Upgrades to existing Experimental Halls

CEBAF Schematic
One of the Jefferson Lab’s two superconducting linear accelerators

**Facility Parameters:**

Continuous Electron Beam Accelerator Facility (CEBAF) parameters:
- Energy: up to 12 GeV
- Current: nA to 90 µA
- Polarization: > 80%
- Relative Energy Spread and Stability: ~10^{-4}
- Pulse Structure: 250 MHz to 1500 MHz
- Beam Power: up to 900 kW
- Controlled Helicity Correlated Properties: <10^{-6} level

Free-Electron Laser parameters:
- Average Power: > 10,000 W
- Average Power: > 10,000 W/1,000W/100W
- Wavelength range: 1-14 microns/0.3-1 micron/0.1 to 5 THz
- Micropulse energy: up to 300 µJ, 20 µJ, 2 µJ
- Pulse length: ~0.1-2 ps FWHM nominal
- PRF: 74.85 MHz ÷ 2x down to 4.68 MHz
- Bandwidth: ~ 0.2–3 % for IR/UV, 100% for THz
- Timing jitter: < 0.2 ps
- Amplitude jitter: < 10% p-p
- Wavelength jitter: 0.02% RMS
- Position/Angle jitter: < 100 um, 10 µrad
- Polarization: linear, > 100:1
- Transverse mode: < 2x diffraction limit
- Beam diameter at lab: 2 - 6 cm

**Major experimental instrumentation and its capabilities:**

**CEBAF (Superconducting Radio Frequency Accelerator):**

From 0.05 (currently) to up to 12 GeV, 100 picoamps to 90 microamps, continuous-wave electron accelerator. Simultaneous beams to three or four experimental Halls with polarization exceeding 80%.

**Hall A:** Two high-resolution magnetic spectrometers

**Hall B:** Large acceptance detector built around a superconducting toroidal magnet in the forward part and a superconducting solenoid in the central part. The detector allows the detection of multiparticle final states.

**Hall C:** Two general-purpose spectrometers (both of high momentum resolution) and experiment-specific equipment

**Hall D:** GlueX spectrometer system, including superconducting solenoidal magnet for detecting multiparticle decays of exotic mesons.

**Superconducting Radio Frequency Technology Facility:**

Superconducting accelerator cavity fabrication, surface treatment, cryomodule assembly and test, and research facilities

**FEL User Facility:** IR/UV upgrade Free Electron Laser designed to provide 10 kW/1 kW of laser light with sub-picosecond pulse length, transform-limited bandwidth, and diffraction-limited emittance. Broadband THz production in 100 fs pulses at up to 74.85 MHz.

**LQCD Aggregate Computer:** Over 100 TFlop/s sustained performance on LQCD applications, with 9000+ cores, 600+ GPU accelerators and 64 Xeon Phi accelerators.

**Applied Research Center:** In collaboration with local colleges/universities and the City of Newport News, share cooperative R&D laboratories in lasers, plasmas and materials

**Nature of user facility:**

DOE Designated National User Facility
Program Advisory Committee/experiment proposals:  
Yes

Number of actual, active users of the facility in a given year:  
Jefferson Lab has some 2900 registered users with more than 1300 actively involved in experiments.

Percentage of users, and percentage of facility use that come from inside the institution:  
As a user facility, very little of the research at Jefferson Lab is conducted by scientists in-house; we would estimate JLab staff to be ~11% of our user community. Percentage of users and percentage of facility use from national users:  
67%

Percentage of users and percentage of facility use from outside the country where your facility is located:  
33%

Fraction of international users outside of geographical region:  
30% are from outside North America

User Group:  
The Jefferson Lab Users Group has over 1300 active users, and its work is coordinated by the User Group Board of Directors (UGBOD). The Chair of the UGBOD represents the users with the Program Advisory Committee and JSA, and with the Laboratory Director.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:  
a) 759 (FTEs)  b) 127 (FTEs)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:  
15 Permanent; (6 Laboratory scientists plus 9 in joint positions with local universities); 8 Postdocs; 11 Graduate Students

Number of postdoctoral researchers:  
13 employed by laboratory directly, 12 employed at universities and reimbursed by the Lab; others are employed/paid by the user community

Number of graduate students resident at the facility:  
~80 (depends on the time of year)

Number of non-resident graduate students with thesis work primarily done at the facility:  
~124 (204 PhDs in progress that include a significant component of JLab research; ~80 are “resident” and ~124 are “non-resident”)

Involvement of undergraduate students in research (approximate average number per year):  
85/year

Special student programs:  
Laboratory programs involve more than 10,000 students each year; they include:

- Hampton University Graduate Student Program (HUGS)
- Becoming Enthusiastic About Math and Science (BEAMS)
- Science Lectures for High School and Middle School Students (Science Series Lectures)
- Physics Fests
- The Department of Energy’s Science Undergraduate Laboratory Internships (SULI)
- Jefferson Lab Science Activities for Teachers Program
- Jefferson Lab High School Summer Honors Program
- Graduate Student Seminar Series
- SURA Fellowship at JLab Program (for Graduate Students)
- Summer Detector and Computer Lecture Program
- SURA/JLab Thesis Prize Program

Future Plans:  
Jefferson Lab is completing construction of its 12 GeV energy upgrade in order to provide new insights into the structure of the nucleon, the transition between hadronic and quark/gluon descriptions of matter, and the nature of quark confinement. The upgraded facility will have unique capabilities world-wide for exploring non-perturbative QCD and hadron and nuclear structure
in the valence region. Longer-range plans for a second upgrade of CEBAF under consideration include a high luminosity medium energy electron ion collider (MEIC) with variable center of mass energies from ~20 - ~70 GeV, upgradable to ~140 GeV. The MEIC would provide unique capabilities for reaching the next QCD frontier, far beyond those available at existing facilities worldwide, and complementary to those planned for the next generation of accelerators in Europe and Asia.
The Triangle Universities Nuclear Laboratory (TUNL) is a Department of Energy Center of Excellence consisting of a consortium of three major universities within the North Carolina Research Triangle area: Duke University, North Carolina State University and the University of North Carolina at Chapel Hill. Three particle-beam accelerator facilities are operated by TUNL: (1) the High Intensity Gamma-ray Source (HIGS), (2) the Laboratory for Experimental Nuclear Astrophysics (LENA), and (3) the tandem laboratory. The facilities are used to study the structure of nuclear matter and to measure nuclear reaction rates important for astrophysics. The capabilities of these facilities enable nuclear structure studies over wide range of nuclear phenomena from nucleon structure to reaction dynamics of few-nucleon systems to collective excitations in heavy nuclei. In addition, these facilities are used for research relevant to national nuclear security, homeland security and the environment.

Technological Descriptions and Capabilities of the Facilities are summarized here.

Head of the Facility:

Prof. Calvin Howell, Director of TUNL

Scientific Mission and Research Programs:

The Triangle Universities Nuclear Laboratory (TUNL) is a Department of Energy Center of Excellence consisting of a consortium of three major universities within the North Carolina Research Triangle area: Duke University, North Carolina State University and the University of North Carolina at Chapel Hill. Three particle-beam accelerator facilities are operated by TUNL: (1) the High Intensity Gamma-ray Source (HIGS), (2) the Laboratory for Experimental Nuclear Astrophysics (LENA), and (3) the tandem laboratory. The facilities are used to study the structure of nuclear matter and to measure nuclear reaction rates important for astrophysics. The capabilities of these facilities enable nuclear structure studies over wide range of nuclear phenomena from nucleon structure to reaction dynamics of few-nucleon systems to collective excitations in heavy nuclei. In addition, these facilities are used for research relevant to national nuclear security, homeland security and the environment. The technical descriptions and capabilities of the facilities are summarized here.

Technical Facilities:

The High Intensity Gamma-Ray Source (HIGS)

The gamma-ray beams at HIGS are produced by Compton backscattering of photons from electron bunches circulating inside the optical cavity of a storage-ring based Free Electron Laser (FEL). The high intensity of this source, about 1000 $\gamma$/s/keV, is mostly due to the combination of the high intra-cavity optical power and the high average beam current in the storage ring (about 100 mA). The layout of the facility is shown in Figure 1. The FEL consists of electromagnetic undulators that are installed in one of the straight sections of the 1.2-GeV racetrack-shaped storage ring. The undulators act as the active elements of optical klystron (OK) FELs with a long optical resonator of 53.7 m in length (mirror-to-mirror distance). The electron accelerator drivers consist of a 180-MeV linac pre-injector, a booster injector of 180 MeV to 1.15 GeV energy range and a race-track shaped storage ring that has an energy range of 250 MeV to 1.15 GeV. The storage ring circumference is about 108 m.

The gamma-ray beams at HIGS are nearly monoenergetic and highly polarized (linear or circular). The beam energy is tunable by adjusting the electron energy and magnetic field strength in the storage ring. The gamma-ray beam energy range is from 1 to 100 MeV. The energy spread of the gamma-ray beam is selectable to about 1% (FWHM) by collimation. The gamma-ray beam specifications and information about the HIGS facility are available on the HIGS website:
The HIGS home page is http://www.tunl.duke.edu/higs/.

Figure 1. Layout of the HIGS accelerator systems with photographs of the booster (upper left) and a section of the electron storage ring (lower right).

The Laboratory for Experimental Nuclear Astrophysics (LENA)

The LENA is a light-ion low-energy accelerator facility dedicated to nuclear astrophysics experiments. The floor diagram of the laboratory is shown in Figure 2. The laboratory has two low-energy electrostatic accelerators that are capable of delivering high-current charged particle beams to target. One is an Electron Cyclotron Resonance (ECR) source on a 200-kV isolated potential platform and the other one is a 1-MV JN Van de Graaff accelerator. The ECR source is capable of delivering proton and deuteron beams of current up to 2 mA on target. The JN Van de Graaff can deliver beam currents up to 200 µA and is used monitor the target thickness or extend measurements to higher energies. Both accelerators are fully computer-controlled and transport proton beams to a common target. Beams from both accelerators are transported to a common target. The standard γ-ray detectors at LENA include a HPGe detector with a configuration of active and passive shielding, surrounded by a NaI annulus. The combination of HPGe + NaI permits coincidence / anti-coincidence, Q-value, and multiplicity cuts to be applied, which often enables measurements of low-yield cross-sections with a quality that is competitive with underground labs. There is also a large solid-angle segmented, position-sensitive NaI detector. For more information, visit http://research.physics.unc.edu/project/nuclearastro/Welcome.html
The Tandem Laboratory

The main accelerator in this laboratory is a FN tandem Van de Graaff that has a maximum terminal voltage of 10 MV. The floor layout of the tandem accelerator laboratory is shown in Figure 3. Negative ions can be injected into the tandem from three sources: (1) a direct extraction negative ion source (DENIS) provides beams of unpolarized H- and D- ions, (2) an atomic beam polarized ion source (ABPIS) provides beams of polarized H- and D- ions, and (3) a helium-ion source provides beams of $^4$He and $^3$He ions. All beams can be pulsed with a repetition rate up to 2.5 MHz. After acceleration, momentum analyzed beam can be delivered to any one of six beam lines. The main target-room equipment includes general-purpose charged-particle scattering chambers, a neutron time-of-flight (TOF) spectrometer system, and an Enge split-pole magnetic spectrometer. A special feature of the facility is the nearly mono-energetic unpolarized and polarized fast neutron beams. The shielded neutron detectors in the TOF spectrometer enable neutron scattering measurements using an unshielded source. Measurements of neutron-induced reactions that require the use of an array of neutron detectors can be carried out in the shielded neutron source area using the collimated neutron beam.

The tandem laboratory also houses the Low-Energy Beam Accelerator Facility (LEBAF) which provides users with polarized and unpolarized beams of protons, deuterons and unpolarized helium ions from 20 to 680 keV. The LEBAF is located in the low-energy bay of the tandem laboratory with beam lines connected to the analyzing magnet at the output of the polarized ion source. The LEBAF is equipped with a 200-kV mini-tandem accelerator and two scattering chambers, one that can be biased to 200 kV. Beam for LEBAF comes from the atomic beam polarized ion source which outputs polarized and unpolarized beams of H+/D+ ions and unpolarized beams of helium ions at energies from 20 to 80 keV. The combined use of the mini-tandem and the 200-kV high-voltage scattering chamber extends the upper energy reach of LEBAF to 680 keV. The beam parameters for the tandem and LEBAF are summarized in Table 1.
Figure 3. Layout of tandem laboratory.

Table 1. Summary of beam parameters in the tandem laboratory

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FN – Tandem Van de Graaff</th>
<th>LEBAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{max}}$ $(p,d)$</td>
<td>20 MeV</td>
<td>680 keV</td>
</tr>
<tr>
<td>Pulse width (fwhm)</td>
<td>2 ns</td>
<td></td>
</tr>
<tr>
<td>Pulse rep. rate</td>
<td>dc to 2.5 MHz</td>
<td></td>
</tr>
<tr>
<td>$I_{\text{max}}$ on target (dc):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unpolarized</td>
<td>5 µA</td>
<td>400 µA (+),</td>
</tr>
<tr>
<td>Polarized</td>
<td>2 µA</td>
<td>3 µA (-)</td>
</tr>
<tr>
<td>Beams</td>
<td>$p, d, ^3\text{He}$, $^4\text{He}$</td>
<td>$p, d, ^3\text{He}$, $^4\text{He}$</td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>&lt;500 eV</td>
<td>&lt;200 eV</td>
</tr>
</tbody>
</table>
The table below briefly characterizes the accelerator facilities at TUNL:

<table>
<thead>
<tr>
<th>HIGS</th>
<th>LENA</th>
<th>Tandem Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 1.2-GeV Storage-ring Free Electron Laser</td>
<td>• 200-keV ECR ion source</td>
<td>• Tandem Van de Graaff (V\text{\text{max}} = 10 MV)</td>
</tr>
<tr>
<td>• Gamma-ray produced by Compton-back Scattering at E_\gamma = 1 – 100 MeV (up to $10^3 \gamma$/s/eV)</td>
<td>• 1-MV JN Van de Graaff accelerator</td>
<td>• CW or pulsed ($f \leq 2.5$ MHz) light-ion beams (p, d, α)</td>
</tr>
<tr>
<td>• Nearly mono-energetic gamma-ray beam (linear and circular polarization)</td>
<td>• Light-ion beams (p, d, α)</td>
<td>• Polarized beams (p, d, n)</td>
</tr>
<tr>
<td>• Two target areas on a single beam line</td>
<td>• One target area</td>
<td>• Fast mono-energetic neutron beams (CW or pulsed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Multiple target areas and beam lines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Collimated neutron beam</td>
</tr>
</tbody>
</table>

The table of TUNL’s major experimental instrumentation and its capabilities:

<table>
<thead>
<tr>
<th>HIGS</th>
<th>LENA</th>
<th>Tandem Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>• HINDA (HI\gamma S NaI Detector Array with NaI shields)</td>
<td>• HPGe detector with NaI shield</td>
<td>• Neutron time-of-flight spectrometer</td>
</tr>
<tr>
<td>• HIFROST (HI\gamma S FROzen Spin Target (polarized hydrogen/deuterium target)</td>
<td>• Scattering chamber for charged-particle induced reactions</td>
<td>• Scattering chamber for charged-particle reactions</td>
</tr>
<tr>
<td>• High resolution γ-ray detector arrays (HPGe and Lanthium Bromide)</td>
<td></td>
<td>• Enge split-pole spectrometer</td>
</tr>
<tr>
<td>• Liquid scintillator arrays for fast neutron detection</td>
<td></td>
<td>• HPGe clover detectors</td>
</tr>
<tr>
<td>• $^3$He counters for slow neutron detection</td>
<td></td>
<td>• Assortment of liquid scintillators for fast neutron detection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High-pressure gas scintillators, e.g., $^4$He and $^3$He</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Attributes</th>
<th>HIGS</th>
<th>LENA</th>
<th>Tandem Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>User facility</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Program Advisory Committee</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Number of actual, active users of the facility in a given year</td>
<td>60</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Percentage of users and percentage of facility use from inside the institution</td>
<td>40/70</td>
<td>100/100</td>
<td>80/100</td>
</tr>
<tr>
<td>Percentage of users and percentage of facility use from national users</td>
<td>45/60</td>
<td>100/100</td>
<td>100/100</td>
</tr>
<tr>
<td>Percentage of users and percentage of facility use from outside the country where your facility is located</td>
<td>55/40</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>Fraction of international users outside of geographical region</td>
<td>35% Europe and Asia</td>
<td>0/0</td>
<td>0/0</td>
</tr>
<tr>
<td>Users group</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Number of (a) permanent staff (b) temporary staff (none)</td>
<td>10.6 FTE</td>
<td>1.4 FTE</td>
<td>2.4 FTE</td>
</tr>
<tr>
<td>Number of theoretical staff employed at the facility:</td>
<td>None</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Number of postdoctoral researchers</td>
<td>8</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Number of graduate students resident at the facility</td>
<td>9</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Number of non-resident graduate students with thesis work primarily done at the facility</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Involvement of undergraduate students in research</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Special student programs</td>
<td>NSF/REU</td>
<td>NSF/REU</td>
<td>NSF/REU</td>
</tr>
<tr>
<td>Future Plans</td>
<td>Intensity upgrade</td>
<td>Pulsed beam</td>
<td></td>
</tr>
</tbody>
</table>
TANDEM ACCELERATOR LABORATORY
WESTERN MICHIGAN UNIVERSITY

Kalamazoo, Michigan

Physics Department
Western Michigan University
MS 5252,
Kalamazoo MI 49008

Telephone: 269-387-4941
Fascimile: 269-387-4939
Email: asghar.kayani@wmich.edu
(Director accelerator laboratory)

University Institute
University funds for operation
NSF MRI grant for recent facility upgrade

Scientific Mission and Research Programs:
The tandem accelerator facility serves a broad spectrum of research activities including atomic, nuclear, condensed matter, and applied physics.

Technical facilities:

Also, the laboratory serves educational goals by providing undergraduate and graduate student laboratory experience, is used in PhD thesis research of graduate students, and supports outreach programs to local secondary-school students.
Tandem schematic layout and photographs of the tandem and the beam line.

**Characterization of the facility:**
6 MV EN Tandem accelerator, light and heavy ions

**Facility Parameters:**
Typical beams (not all-inclusive list):
- $^1$H 2-12 MeV 1µA
- $^4$He 2-20 MeV 100pµA
- $^{12}$C 4-30 MeV 1µA
- $^{37}$Cl 4-40 MeV 1µA
- $^{63}$Cu 4-40 MeV 1µA

**Major experimental instrumentation and its capabilities:**
- Electron and Ion spectrometer for energy and angular analysis
- General purpose scattering chamber (usable for RBS, NRA, PIXE, PIGE and RNRA)
- X-ray and γ-ray spectroscopy instrumentation

**Nature of user facility:**
No

**Program Advisory Committee/experiment proposals:**
No

**Number of actual, active users of the facility in a given year:**
10-12 (faculty, staff, graduate students)

**Percentage of users, and percentage of facility use that come from inside the institution:**
Nearly all

**Percentage of users and percentage of facility use from national users:**
Occasional

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
Occasional

**Fraction of the international users from outside geographical region:**
All

**User Group:**
No

**Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:**

a) 4-5
b) 4-5

**Number of theoretical staff employed at the facility: permanent; postdoctoral, students:**
0

**Number of postdoctoral researchers:**
Presently 0

**Number of graduate students resident at the facility:**
8-10

**Number of non-resident graduate students with thesis work primarily done at the facility:**
0

**Involvement of undergraduate students in research (approximate average number per year):**
3-4

**Special student programs:**
Modern physics laboratory, Advanced laboratory for graduate students, Kalamazoo Area Math and Science Center Mentorship projects

**Future Plans:**
New Pelletron charging system, and new data acquisition system installed 2004. New ion sources installed 2010
TANDAR LABORATORY
COMISIÓN NACIONAL DE ENERGÍA ATÓMICA
PHYSICS DEPARTMENT

Buenos Aires, Argentina

Av. General Paz 1499
San Martín
Pcia. de Buenos Aires
B1650KNA
Argentina

Telephone: (54-11) 67 72 71 16
Facsimile: (54-11)67 72 71 21
Email: duran@tandar.cnea.gov.ar
www.tandar.cnea.gov.ar/

Governmental agency
Government budget (CNEA)
Funding agencies (mainly CONICET and ANPCYT)

Dr. Norma Boero (President of CNEA)

Head of the facility:
Dr. Gerardo García Bermúdez

Scientific Mission and Research Programs:
The main experimental and theoretical research lines related to Nuclear Physics and its applications are the following: Low-energy nuclear physics: Nuclear structure, nuclear reactions, collective nuclear excitations and giant resonances, break-up reactions and their influence on fusion reactions involving weakly bound nuclei; fusion barrier distributions. High-energy nuclear physics: Hadronic models based on QCD. Phase structure of strong interactions. A result of basic research activities has been the application of various experimental nuclear physics techniques to other fields of knowledge: biomedicine, environment, material science, nuclear astrophysics. In the biomedical area it is worth mentioning a project related to accelerator-based Boron Neutron Capture Therapy (BNCT), including aspects related to the development of a high intensity low-energy proton accelerator. A heavy-ion microbeam facility for the study of biological and physical problems with high spatial resolution has recently started to operate.
Technical facilities:

Characterization of the facility:
20 MV electrostatic tandem accelerator

Facility Parameters:
An example of frequently used beams are: protons, lithium, beryllium, carbon, oxygen, fluorine, sulphur, nickel, iodine, gold, with typical on-target intensities in the range of 1 to 100 particle-nanoamperes and energies of a few MeV/nucleon.

Major experimental instrumentation and its capabilities:
Microbeam facility (beam spots of about 1μm²) with high resolution X-ray detection.
QDD magnetic spectrometer.
External beam facility with on-line dose determination.
Heavy-ion identification based on a time-of-flight facility (start and stop signals derived from microchannel plates) followed by a Bragg spectrometer or solid state detectors.
30-inch diameter multipurpose scattering chamber.
Irradiation chamber for the simulation of outer-space environmental conditions.

Nature of user facility:
Unofficially, user facility

Program Advisory Committee/ experiment proposals:
No

Number of actual, active users of the facility in a given year:
51
Percentage of users, and percentage of facility use that come from inside the institution:

Users 80%
Facility use 90%

Percentage of users and percentage of facility use from national users:

Users 80%
Facility use 90%

Percentage of users and percentage of facility use from outside the country where your facility is located:

Users 20%
Facility use 10%

Fraction of the international users from outside of geographical region:

30%

User Group:

40 registered members in the users group:

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) 46 (only those directly related with nuclear-physics research and/or the facility have been considered)
b) 12 (only those directly related with nuclear-physics research and/or the facility have been considered)

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:

4 (only the fraction of theoretical staff directly related with nuclear-physics research has been considered)

Number of postdoctoral researchers:

3

Number of graduate students resident at the facility:

9 (only those directly related with nuclear-physics research and/or the facility have been considered)

Number of non-resident graduate students with thesis work primarily done at the facility:

None

Involvement of undergraduate students in research (approximate average number per year):

10

Special student programs:

An extension course for senior high-school students is carried out yearly (once a week; from April to November)
LABORATÓRIO ABERTO DE FÍSICA NUCLEAR – LAFN
UNIVERSIDADE DE SÃO PAULO
INSTITUTO DE FÍSICA

Departamento de Física Nuclear
LAFN – Laboratório Aberto de Física Nuclear

Campus of USP –
City of São Paulo, Brazil

Laboratório Aberto de Física Nuclear – LAFN
Departamento de Física Nuclear - IFUSP
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BRAZIL

Telephone: 55-11-3091-6939/ 55-11-3091-7100
Facsimile:55-11-3031-2742
Email: seclinac@dfn.if.usp.br
http://www.dfn.if.usp.br/
www.dfn.if.usp.br/pagina-lafn/index.html

The LAFN is part of the Nuclear Physics Department of the Institute of Physics, University of São Paulo, a public university funded by the Government of the State of São Paulo.

Operation (including salaries), is funded by the University. Maintenance, upgrades, etc. are funded by several state agencies like FAPESP (State of São Paulo), CNPq and Finep (federal).

Dmitri M. Guitman – Head of the Nuclear Physics Department

Head of the facility:
Dirceu Pereira - Director of LAFN (until March 2005)
Roberto Vicençotto Ribas – Director of LAFN (from March 2005-March 2007)

Scientific Mission and Research Programs:
The LAFN is a low energy nuclear physics laboratory, devoted both to basic and applied nuclear physics. Research is mainly in Nuclear Reactions (light and heavy ions), Nuclear Structure and Material Analysis. Recently a device to produce a secondary radioactive beam has been installed and research with Radioactive Beams is also underway. A large part of the research programs involve graduate students from USP.

Technical facilities:
Characterization of the facility:

NEC 8UD (8 MV) Tandem electrostatic accelerator. A superconducting linear accelerator for heavy-ions is under construction.

Facility Parameters:

Stable Beams: p, d, $^6$Li, $^{10,11}$B, $^{12,13}$C, $^{16,17,18}$O, $^{19}$F, $^{28,29,30}$Si, $^{35,37}$Cl

Intensities: from ~0.3 to ~2 microAe

Energies: 16 MeV (p) to 80 MeV (Si)

Radioactive ion beams delivered by RIBRAS (Radioactive Ion beams Brasil) facility:

- $^8$Li (10$^6$ pps/microAe, E< 32 MeV)
- $^6$He (10$^5$ pps/microAe, E<28 MeV)
- $^7$Be (10$^5$ pps/microAe, E<31 MeV)

Major experimental instrumentation and its capabilities:

RIBRAS: 2 Superconducting solenoids (for secondary radioactive beam)

General purpose scattering chamber (about 50 cm radius)

Large volume scattering chamber (about 80 cm radius, ~2 m long)

Gamma-ray spectrometer (4 HPGe with AC shield + particle ball)

Nature of user facility:

Yes, unofficially. Even if owned by the University, the facility is operated like a National Lab. and is open to users from all Institutions.

Program Advisory Committee/experiment proposals:

Yes. The PAC consists of five members, one from outside Brazil and meets once in the year. 200 days/year are distributed, 5days /week, 24h/day. Last PAC meeting had 440 days requested and 200 approved.

Number of actual, active users of the facility in a given year:

Average from last two years: about 100 (researchers and graduate students) were involved in experiments approved by the PAC and effectively realized.

Percentage of users, and percentage of facility use that come from inside the institution:

About 90% of the users are from the home institution. Nonetheless, the number of outside users is increasing and from the experiments proposed at the last PAC, we expect about 20% of outside users for the current year.

Percentage of users and percentage of facility use from national users:

All users are, with rare exceptions, from Brazilian institutions.
Percentage of users and percentage of facility use from outside the country where your facility is located:

Until recently very little, except for eventual collaborators of the local groups.

However recently the RIBRAS facility is attracting international collaborators (Argentina, Cuba, Japan, Spain, France)

Fraction of the international users from outside of geographical region:

Recently the RIBRAS facility is attracting international collaborators (Japan, Spain, France)

User Group:

Yes, the formal user's group has 100 members. Every year the users group leader is elected by the users.

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:

a) 17 faculty staff and 30 technical staff
b) 17 faculty staff

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
3 staff members and 10 pos-docs and students.

Number of postdoctoral researchers:
8

Number of graduate students resident at the facility:
34

Number of non-resident graduate students with thesis work primarily done at the facility:
6

Involvement of undergraduate students in research (approximate average number per year):
20

Special student programs:

Yes. Every two years there is a training program (about 3 month duration) four undergraduate students join the lab and four fresh graduate students coming from other institutions.

The staff members of the facility also participate actively in the organization of Biennial Nuclear Physics Summer Schools (theoretical and experimental) with participation of many students from over all Brazil and South America.

In Feb 2004 we held the XII Jorge Andre Swieca Experimental Nuclear Physics Summer School a 2 week of duration involving, 50 students from all South America using the RIBRAS facility that has just begun its operation.

In Feb 2005 we held the XII Jorge Andre Swieca Theoretical Nuclear Physics Summer School, a 1 week of duration and 70 students from all South America, where Prof. Shiguero Kubono from Tokyo, Prof. Jeff Tostevin from Surrey, Prof. Brian Serot from Indiana, and Dr R. Clark from LBL were some of the lecturers.

Future Plans:

The main goal for the near future is to finish the installation of the LINac post-accelerator, that has been delayed for many years due to financial difficulties. The new Radioactive Beam facility (RIBRAS) that became operational in January 2004 brought new research possibilities and several groups have many new experiments approved that will use this device.
Head of the facility:
  Prof. Rodrigo Prioli

Scientific Mission and Research Programs:
The Laboratory started in the 70’s, as a Nuclear Physics Lab.

In the 80’s the activities were directed towards applications such as Material Science (RBS, PIXE), Environment Analysis and Atomic Physics research. In the 90’s, the lines on Atomic Collisions in gases and Surface Physics & Analysis were included.

Nowadays, Nanotechnology and Biological Material Analysis are also included.

Technical facilities:

Experiment Room

90° magnet

Characterization of the facility:
The accelerator is a 4 MeV single end Van de Graaff.

Facility Parameters:
Proton to argon beams.
Radiofrequency ion source.
Analyzing magnet: ME = 40
Major experimental instrumentation and its capabilities:
Several TOF systems for ion detection. (identification, angular and energy distributions)
RBS and PIXE systems
Nature of user facility:
It is operated by the staff members, very often with external cooperation.
Program Advisory Committee/experiment proposals:
No.
Number of actual, active users of the facility in a given year:
About 10 groups a year. Each group has typically 3 persons and has the beam for 5 days per week. Nevertheless it is possible to operate by night and week ends, the accelerator is used only during the day.
Percentage of users, and percentage of facility use that come from inside the institution:
80%
Percentage of users and percentage of facility use from national users:
100%. Of course, foreign professors come as visiting researchers.
Percentage of users and percentage of facility use from outside the country where your facility is located:
-
Fraction of international users outside of geographical region
Visiting professors come from US or Europe.
User Group:
4 groups of 3 permanent persons
Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
a) 7 professors  b) 10 persons
Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
None
Number of postdoctoral researchers:
4
Number of graduate students resident at the facility:
10
Number of non-resident graduate students with thesis work primarily done at the facility:
1 or 2
Involvement of undergraduate students in research (approximate average number per year):
3
Special student programs:
None
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Government Owned Facility

Loreto Villanueva, Executive Director

Head of the facility:
Mario Avila-Sobarzo

Scientific Mission and Research Programs:
Neutron-deficient Radioisotope Production for PET applications, Basic Research on targets for radioisotope production

Technical facilities:

Not available but should be possible to obtain from the institutional web site (www.cchen.cl)
Characterization of the facility:
Accelerator cyclotron, Cyclone 18/9 Manufacture by IBA Belgium. Eight targets, and one external Beam Line Transport with Switching Magnet.

Facility Parameters:
18 MeV Proton and 9 MeV Deuteron fixed energy beams. Proton beam intensity 60 uA. Deuteron beam intensity 30 uA.

Major experimental instrumentation and its capabilities:
8 targets positions at the maximum radius of extraction with liquid, solid and gas targets plus one external beam line with a 5 position switching magnet.

Program Advisory Committee/experiment proposals:
100% from inside users

Number of actual, active users of the facility in a given year:
Two groups from the institution, one for PET RI RF production another for accelerator development. At least 3 groups from University: a) nuclear astrophysics, b) solid state physics and c) elementary analysis.

Percentage of users, and percentage of facility use that come from inside the institution:
100% from inside users.
100% from inside

Percentage of users and percentage of facility use from national users:
None

Percentage of users and percentage of facility use from outside the country where your facility is located:
None

Fraction of international users outside of geographical region:
None

Number of a) total laboratory staff (all categories) b) Scientists on staff with doctoral degree:
5
1

Number of theoretical staff employed at the facility: permanent; postdoctoral, students:
5, 0, 1
3, 2, from 3 up

Number of postdoctoral researchers:
1

Number of graduate students resident at the facility:
0

Number of non-resident graduate students with thesis work primarily done at the facility:
1

Involvement of undergraduate students in research (approximate average number per year):
2

Special student programs:
None

Future Plans:
I.- GMP facility for PET RF Production.
II.- Extended Beam Line Transport (from SM) for: a) Neutron dosimetry. b) 18 MeV PIXE analytical facility for elemental NDA analysis.
Head of the facility:
Dr. Jose Roberto Morales

Scientific Mission and Research Programs:
This is the only charged particle accelerator operating in the Chilean university system. The principal features of its scientific mission are: a) to perform research in basic and applied nuclear physics; b) to provide training to undergraduate and graduate students in experimental nuclear physics and related areas.

The current research programs are:

a) Applications of accelerator-based IBA methods to multidisciplinary studies like elemental characterization of airborne particulate matter from urban and remote sites, elemental composition of archaeological materials, bioaccumulation of metals in tissues, and others.

b) Measurement of nuclear reaction cross sections of medical and astrophysical interest.

c) Measurement of stopping power in a variety of metallic foils.

Characterization of the facility:

**Facility Parameters:**
Single charge ions of protons, deuterons, alpha, Xe, Ne. Variable energy in the range from 300 keV to 3500 keV. Beam intensities from less than one nanoamp. to tens of microamps.

**Major experimental instrumentation and its capabilities:**
Four dedicated irradiation chambers:
1. PIXE chamber. Manual and remote control of target position. Thin and thick targets.
2. ORTEC scattering chamber for RBS and stopping power measurements.
3. CINEL-Strumenti Scientifici chamber for simultaneous PIXE and RBS. Remote controlled target positions.
4. Multipurpose chamber for ion implantation and nuclear reaction measurements. X-ray and gamma spectroscopic systems. HPGe, HPSi, Si(Li), Na(Tl), and surface barriers detectors. CAMAC multiparametric data acquisition system.

**Nature of user facility:**
From the university system.

**Program Advisory Committee/experiment proposals:**
There is a Users Advisory Committee

**Number of actual, active users of the facility in a given year:**
6 in nuclear physics and applications
2 (plus students) in thin films and material science.

**Percentage of users, and percentage of facility use that come from inside the institution:**
90 % users from the institution
100 % use from inside

**Percentage of users and percentage of facility use from national users:**
10 % users from other national institution
5 % use by users from other national institution

**Percentage of users and percentage of facility use from outside the country where your facility is located:**
None at present

**Fraction of international users outside of geographical region:**
None at present

**User groups:**
Nuclear and IBA applications: 6
Material Science and thin films: 2 (plus students)
Technical developments: 2 (one from other national institution)

**Number of a) permanent staff (all categories) and b) Scientists on staff:**
- a) 7 permanent (plus one part time)
- b) 3 Ph.D., 3 M.Sc.

**Number of postdoctoral researchers:**
1

**Number of graduate students resident at the facility (>80 % of their time):**
1 (>80% of their time)

**Number of non-resident graduate students with thesis work primarily done at the facility:**
2 (<80% of their time)

**Involvement of undergraduate students in research:**
20

**Special student programs:**
2 internships during one month in summer student vacation period

**Future Plans:**
Development of oxygen, nitrogen, argon and krypton beams
Get a new ion source