A Strategic Plan for the Argonne Tandem Linac Accelerator System

Physics Division
Argonne National Laboratory
Argonne, IL

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Introduction

This strategic plan is developed jointly by the ATLAS user community and the Physics Division at Argonne National Laboratory. This plan is available to the entire ATLAS user community and is updated as the need arises. In practice, the community discusses this plan at regular ATLAS Users Workshops, the most recent of which was held on April 8, 2006. The users' executive committee and ATLAS management then work together to incorporate the outcome of these workshops into the strategic plan.

This plan provides the scientific and strategic vision for ATLAS, the goals for its future capabilities and the expected path forward in light of realistic budget constraints.

Strategic Plan

Mission: **The mission for 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.**

This mission requires identifying the highest priority scientific goals, and allocating resources to optimize the research output of the facility. The current scientific goals are fully consistent with those defined in the NSAC 2002 Long Range Plan and the Office of Science 2004 Strategic Plan. The optimization of the research involves the following elements:

1. Effective long-term operation of the accelerator.
2. Development of new accelerator capabilities to enable new high priority research opportunities.
3. Effective support of the experimental program.
4. Development of new experimental capabilities to enable new high priority research opportunities.
5. Nurturing the scientific and technical base of the low energy research program and helping to develop the high-quality workforce for future initiatives.

This last element is not discussed explicitly below but is a major factor in the delivery of the entire research program, including the need for young researchers to be involved in equipment development and new research initiatives.

Major Scientific Goals

The major scientific goals below have been identified for the ATLAS research program. In each case the anticipated experimental program for the next five years, is based on the ideas of the user community. Further elaboration of these ideas can be found in a document summarizing the outcome of the April 8 Users Workshop which is available at http://www.phy.anl.gov/atlas/User_Meeting/ATLAS_workshop_summary_08Apr06.pdf. Appendix I contains a comparison of the various aspects of the program with the milestones developed by NSAC for nuclear physics in 2004.

I. Understanding the stability and structure of nuclei as many-body systems built of protons and neutrons bound by the strong force;

The following scientific issues have been identified as most urgent by the ATLAS users:

- comparisons of the properties of neutron-rich, light nuclei (A<20) with *ab-initio* calculations (Greens function Monte Carlo, no-core shell model) and other approaches,
- the study of properties associated with the isospin degree of freedom and the search for increased isospin breaking away from stability,
- the search for signatures of a possible new form of pairing (S=1,T=0) in N=Z nuclei near the proton drip-line for 50<A<100,
- the impact of weak binding on the structural properties of nuclei at the proton drip line and beyond such as shell structure, deformation, and the characteristics of proton radioactivity,
- the delineation of the structural properties of the heaviest nuclei (Z>100),
- the exploration of the properties of neutron-rich nuclei (changes in shell structure, pairing, single-particle strength, new types of collective excitations, and other effects associated with a large neutron excess),
- the identification of new collective modes and the search for their characteristic spectral signatures,
- the study of the properties of the nuclei at the highest spins and excitation energies. This includes the exploration of the interplay between collective and single particle degrees of freedom, the search for new nuclear shapes (hyperdeformation) and the transition from an ordered to a chaotic regime with temperature.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities,
Increased ATLAS beam energies,

Development of unique new radioactive beam capabilities, especially for neutron-rich beams,
Continued effective operation and improvement of Gammasphere,
New instrumentation for transfer reaction studies in inverse kinematics.

II. Exploring the origin of the chemical elements and their role in shaping the reactions that occur in the cataclysmic events of the cosmos;

The following scientific issues have been identified as most urgent by the ATLAS users:

- cross section measurements for reactions within the CNO cycle, and in particular for the $^{12}C(\alpha,\gamma)^{16}O$ reaction,
- the determination of the most critical reaction paths responsible for the break-out of the hot CNO cycle and for the first stages of the rp-process,
- the competition between (α,p) and (p,γ) reactions along the rp-process path,
- the identification of waiting point nuclei along the rp-process path,
- the determination of the end-point of the rp-process path near A~100,
- the measurement of the mass and decay properties of neutron-rich nuclei close to the r-process path,
- the development of the surrogate reaction technique for the determination of reaction yields along the s- and r-process paths.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities,
Improved beam purity for exotic beams,
Access to neutron-rich beams,
New instrumentation for reaction studies in inverse kinematics,
Continued effective operation and improvement of Gammasphere.

III. Understanding the dynamics governing interactions between nuclei at energies in the vicinity of the Coulomb barrier;

The following scientific issues have been identified as most urgent by the ATLAS users:

- the study of the hindrance of fusion at extreme sub-barrier energies,
- the impact of nuclear structure (deformation, shell structure, diffuseness) on fusion, especially for reactions leading to Z>100 nuclei,

- the impact of neutron excess on nuclear reactions in the vicinity of the Coulomb barrier,
- the determination of the proton-neutron asymmetry dependence of the surface and volume terms of the nuclear level density.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities,
Access to neutron-rich beams.

IV. Testing with high accuracy the fundamental symmetries of nature by taking advantage of nuclei with specific properties;

The following scientific issues have been identified as most urgent by the ATLAS users:

- tests of the conserved vector current (CVC) hypothesis and the unitarity of the first row of the Cabibbo-Kobayashi-Maskawa (CKM) matrix from studies of superallowed $0^+ \rightarrow 0^+$ Fermi decays,
- searches for possible extensions of the Standard Model by improving by one order of magnitude or more limits on scalar, tensor and right-handed components to the electro-weak interaction.

This program requires:

Effective operation of ATLAS,
Increased ATLAS beam intensities.

Smaller scale, complementary efforts exploit the exceptional and often unique capabilities of ATLAS: for example, accelerator research experiments, the irradiation of samples for materials research, or developing accelerator mass spectrometry techniques for applications in environmental studies, oceanography, astrophysics, fundamental interactions, and any other area of basic science where they apply. These efforts address important physics issues and, in some instances, programs help focus improvements in overall performance of the facility. However, they do not set the priorities for new developments of ATLAS and the associated instrumentation.

Initiatives

Based on the requirements to reach these goals, the following initiatives have been identified to carry out this research program:

- Expand the range of unstable, neutron-rich beams available at ATLAS with the Californium Rare Ion Breeder Upgrade (CARIBU),
- Extend the energy range of ATLAS for inverse reactions by completing the ATLAS upgrade,
- Improve the beam intensities available at ATLAS by the continuous upgrade of the oldest elements of the superconducting linac, and steady improvements in ion source capabilities,
- Improve the purity of exotic beams produced by the in-flight technique by the introduction of a RF chopper,
- Develop major new instrumentation for reaction studies with unstable beams, the leading example being the HELIcal Orbit Spectrometer (HELIOS),
- Continue to maintain and upgrade Gammasphere as well as the other state-of-the-art instrumentation present at ATLAS,
- Develop high-efficiency detection systems for the complete characterization of rare decay modes along the proton drip line, in neutron-rich nuclei and in the heaviest elements.

As ATLAS is presently the only low-energy national user facility focusing on experiments with stable beams, there is an inherent responsibility to make stable beams available to the national community. However, the priorities expressed in the Office of Nuclear Physics performance measures and strategic plan, as well as the scientific goals given above, make it imperative that opportunities with unique radioactive beams at ATLAS continue to be pursued when identified as being important science by the community and endorsed by the Program Advisory Committee as high priority.

Priorities

It is the view of the user community and of the management of the Physics Division that 7 days/week operation of ATLAS at all cost is the wrong approach, even under scenarios with somewhat improved funding, and that a return to this desired level of operations is warranted only if investments in the maintenance and upgrade of the accelerator and the associated instrumentation can be made. This approach will help realize the potential of the science for the low-energy community by assuring the long term future of operations at ATLAS.

An advanced exotic beam facility is a major priority for the nuclear science community, Argonne management and the users of ATLAS. It is recognized that the highest priority is to bring such a facility into being. At the same time the science and the community must be carefully nurtured through the optimized use of steadily upgraded existing facilities.

With this guidance and requirements of the science, the priorities of ATLAS for the near future in the context of the FY2007 President's budget request are:

1. Effective operation of the ATLAS facility, including operations and experiment support, at a minimum level of 5500 hours/year while new upgrades are carried out: this is a necessary condition to address (a) the large demand for low cross section experiments and for the detection of rare events, (b) the need of a large user community for flexibility in scheduling and operations, and (c) the need to develop new beams, especially exotic beams, and novel instrumentation. The FY07 budget allows staffing levels to increase to the point where this level of operation can be accommodated. The FY07 budget also leads to higher beam hours once CARIBU construction is complete. If funding is reduced from the FY07 levels, operation would remain at five days a week.

2. Development of new accelerator capabilities targeted towards these scientific goals:

    a) A major upgrade of the reaccelerated radioactive beam capability: the implementation of the CARIBU project will provide neutron-rich species that are not available elsewhere in the pre-RIA era. This project represents an important, unique step in the exploration of neutron-rich nuclei (Project started 1Q FY06, anticipated completion 1QFY09).

    b) The energy upgrade of ATLAS: the 30% increase in the maximum energy for ions in the 100-200 mass range is an essential ingredient of a research program probing nuclear states via transfer reactions in inverse kinematics with stable and rare isotopes in the 10 MeV/u range, where the velocities of the nucleons of interest in the projectile and target are well matched (Fully funded, anticipated completion FY07).

    c) The improvement of in-flight radioactive beams capabilities: this includes the installation of an RF chopper for the in-flight beam program to improve the beam purity for these short-lived, low-intensity beams and enable measurements of lower cross section for nuclear astrophysics.

3. Development and operation of experimental capabilities: this includes

    a) The construction and operation of HELIOS: this device represents an optimized solution to the challenge of measuring transfer reactions inverse kinematics at all relevant scattering angles.

    b) The construction of the X-array: this high-resolution, high-efficiency array for the focal plane of the FMA is an essential component for decay spectroscopy of evaporation residues produced with sub-microbarn cross sections such as very heavy nuclei or proton emitters.

c) The continued operation and upgrade of Gammasphere in order to capitalize on the world's most powerful gamma-ray detector.

d) Increased user support including significantly upgraded target-making capabilities.

e) Support to accommodate new detector systems, especially Gretina, in accord with the community-wide plans for such major instruments.

4. Restoration of full 7 day per week operations of ATLAS.

In the longer term, a major priority, endorsed by the user community, will be substantial expansions in capabilities based on ATLAS. These will be required to provide the U.S. low-energy community with the opportunity to assume a continued leadership role in the rapidly expanding science of physics with rare isotopes.

Appendix I: The ATLAS Strategic Plan and the Performance Measures

The research topics I - IV listed under “Major Scientific Goals” in the Strategic Plan for ATLAS are in line with the priorities of the nuclear physics community and of the DOE’s Office of Science as expressed in their most recent plans. This is shown here by confronting them with the NSAC performance measures.

(1) Nuclear Structure & Reactions milestones:

The 2006 milestone on changes in shell structure and collective modes as a function of neutron and proton number from the proton drip line to moderately neutron-rich nuclei is addressed under goal (I) in a large number of the identified scientific issues, *i.e.*,

- comparisons of the properties of neutron-rich, light nuclei (A<20) with ab-initio calculations (Greens function Monte Carlo, no-core shell model) and other approaches,
- the study of properties associated with the isospin degree of freedom and the search for increased isospin breaking away from stability,
- the search for signatures of a possible new form of pairing (S=1,T=0) in N=Z nuclei near the proton drip-line for 50<A<100,
- the impact of weak binding on the structural properties of nuclei at the proton drip line and beyond such as shell structure, deformation, and the characteristics of proton radioactivity,
- the exploration of the properties of neutron-rich nuclei (changes in shell structure, pairing, single-particle strength, new types of collective excitations, and other effects associated with a large neutron excess),
- the identification of new collective modes and the search for their characteristic spectral signatures,
- the study of the properties of the nuclei at the highest spins and excitation energies

The 2007 milestone on the properties of the heaviest elements above Z ~ 100 is addressed squarely by dedicated items under

- goal (I), *i.e.*, the delineation of the structural properties of the heaviest nuclei (Z>100),
- goal (III), *i.e.*, the impact of nuclear structure (deformation, shell structure, diffuseness) on fusion, especially for reactions leading to Z>100 nuclei

Contributions by the ATLAS research program towards the 2009 milestone on spectroscopic information of crucial doubly-magic nuclei far from stability will be coming from the studies of neutron-rich nuclei with CARIBU described under goal (I), i.e.

- the exploration of the properties of neutron-rich nuclei (changes in shell structure, pairing, single-particle strength, new types of collective excitations, and other effects associated with a large neutron excess),

Research at ATLAS is unlikely to contribute to the second 2009 milestone on the determination of the neutron drip line up to Z=11. This milestone is likely to require the production of the exotic beams of interest through fragmentation, a process requiring beam energies outside the facility's energy range.

The 2010 milestone on the completion of GRETINA is outside the range of the ATLAS strategic plan. Nevertheless, it should be noted that sensitive studies of structural evolution and collective modes mentioned in this milestone match with some of the issues mentioned under topic (I), *i.e.*,

- the identification of new collective modes and the search for their characteristic spectral signatures,
- the study of the properties of the nuclei at the highest spins and excitation energies. This includes the exploration of the interplay between collective and single particle degrees of freedom, the search for new nuclear shapes (hyperdeformation) and the transition from an ordered to a chaotic regime with temperature.

Thus, the ATLAS research program could contribute to the 2010 milestone, if the instrument was to be based at the facility within the appropriate time frame.

The 2013 milestone on microscopic calculations, density functionals, many-body symmetries, collective modes and effective forces is primarily theoretical in nature. However, it is clear that the ATLAS research program as expressed in topics (I) and (III) will provide essential experimental input which will help define the interactions and correlations required for the successful descriptions implied by the milestone.

(2) Nuclear Astrophysics milestones:

The 2007 milestone on transfer reactions on r-process nuclei near the N=50 and N=82 closed shells cannot be addressed directly at ATLAS until beams from CARIBU become available. However, the ATLAS research program continues to contribute structure information for neutron-rich nuclei in the two regions (around ^{82}Ge and ^{132}Sn) as outlined under topic (I), *i.e.*,

- the exploration of the properties of neutron-rich nuclei (changes in shell structure, pairing, single-particle strength, new types of collective excitations, and other effects associated with a large neutron excess)

The 2009 milestone on the measurement of properties of and reactions on selected proton-rich nuclei in the rp-process is addressed squarely under topic (II), *i.e.,*

- the determination of the most critical reaction paths responsible for the break-out of the hot CNO cycle and for the first stages of the rp-process,
- the competition between (α,p) and (p,γ) reactions along the rp-process path,
- the identification of waiting point nuclei along the rp-process path,
- the determination of the end-point of the rp-process path near A~100,

The second 2009 milestone is theoretical in nature (flame propagation in type 1a supernovae) and is not addressed directly at ATLAS.

The 2010 milestone on the reduction by a factor of two of uncertainties of the most crucial stellar evolution nuclear reactions is also addressed explicitly under topic (II), *i.e.*,

- the cross section measurements for reactions within the CNO cycle, and in particular for the $^{12}C(\alpha,\gamma)^{16}O$ reaction,
- the determination of the most critical reaction paths responsible for the break-out of the hot CNO cycle and for the first stages of the rp-process,

The ATLAS research program contributes to the 2011 milestone on neutron capture reactions to constrain s-process isotopic abundances under topic (II), *i.e.,*

- the development of the surrogate reaction technique for the determination of reaction yields along the s- and r-process paths.

The availability of neutron-rich beams from CARIBU will allow the ATLAS research program to contribute significantly to the 2012 milestone on measuring masses, lifetimes, spectroscopic strengths and decay properties of neutron-rich nuclei in the supernova r-process. This is mentioned explicitly in topic (II) under

- the measurement of the mass and decay properties of neutron-rich nuclei close to the r-process path,

Furthermore, some of the issues regrouped under topic (III) will also contribute to this milestone, *i.e.,*

- the study of the hindrance of fusion at extreme sub-barrier energies,
- the impact of neutron excess on nuclear reaction in the vicinity of the Coulomb barrier.
- the determination of the proton-neutron asymmetry dependence of the surface and volume terms of the nuclear level density.

The two 2013 milestones are concerned with simulations of core collapse supernovae and neutron star structure and evolution that are not addressed directly by the ATLAS research program.

(3) Contributions to milestones in other sub-fields

The ATLAS program contributes (directly or indirectly) to some of the milestones in Neutrinos, Astrophysics and Fundamental Interactions. For example, experiments at ATLAS on the determination of the ^{8}B neutrino spectrum contribute to the 2007 milestone on solar ^{8}B neutrinos.

The two scientific issues described under topic (IV) address directly the 2010 milestone on neutron and nuclear β-decay and physics beyond the standard model. These are:

- tests of the conserved vector current Cabibbo-Kobayashi-Maskawa (CKM) unitarity of the first row of the matrix from the superallowed $0^+ \rightarrow 0^+$ Fermi decays,
- searches for possible extensions of the Standard Model by improving by one order of magnitude or more limits on scalar, tensor and right- handed components to the electro-weak interaction.

The ATLAS program also contributes indirectly to a new lifetime measurement of the neutron by determining the purity of the ^{4}He gas used in the NIST experiment through an AMS measurement.