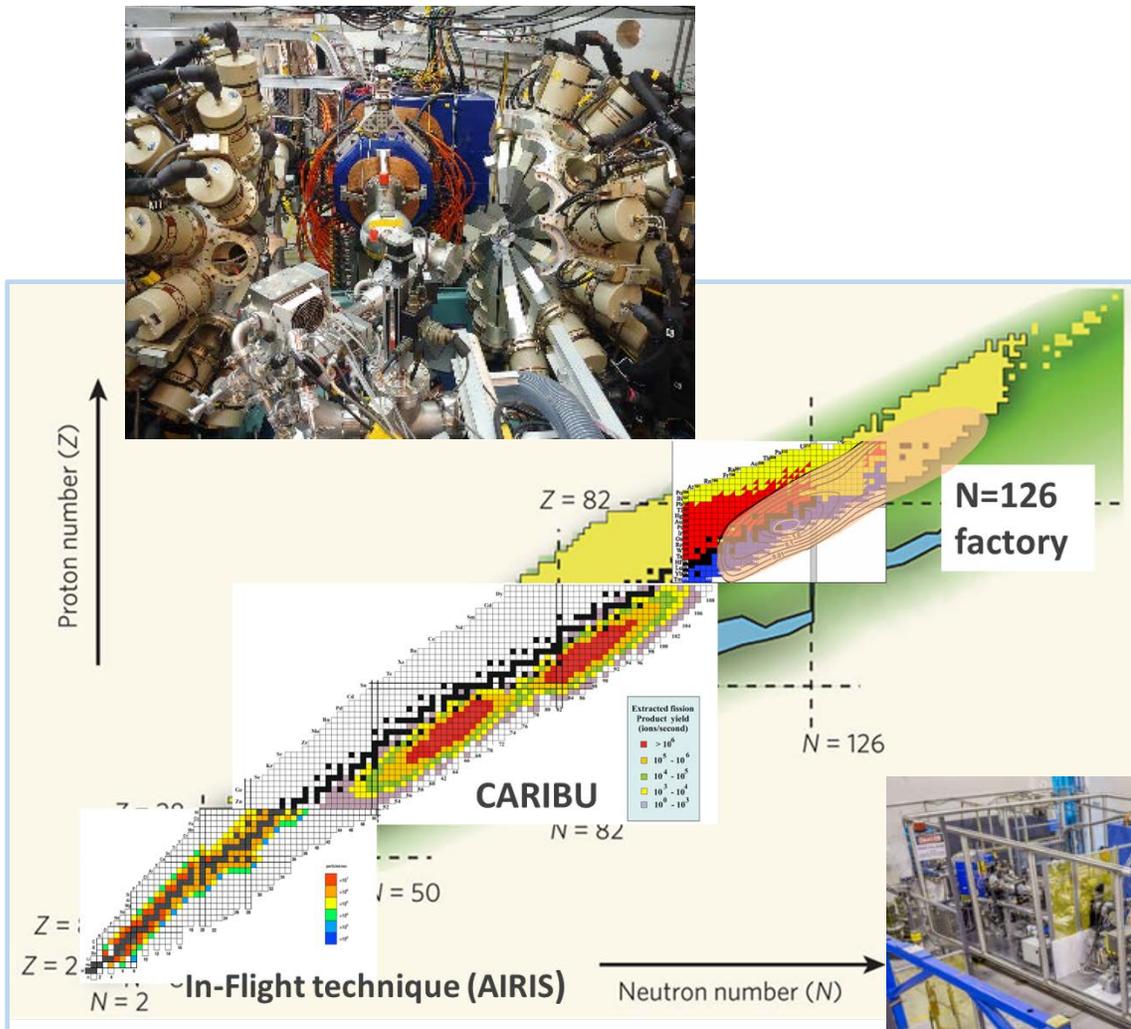


# 2018 Strategic Plan for the ATLAS Accelerator Facility Physics Division, Argonne National Laboratory



## Contents

Executive Summary .....	3
Introduction.....	5
Strategic Plan .....	6
Mission:.....	6
Major Scientific Programs: .....	7
Initiatives: .....	12
Approach:.....	13
Timeline for implementation and personnel needs:.....	18
Appendix A: 10-year staffing plan .....	20
Appendix B: Additional ATLAS contributions to the DOE mission .....	23

## **Executive Summary**

The 2014 ATLAS strategic plan laid out a physics program that addressed the needs of the low-energy user community, as presented in the May 15-16, 2014 ATLAS Users Workshop. Implementation of this plan involved a significant program of accelerator and experimental equipment development and construction to enable the ATLAS community to target key questions in nuclear structure, nuclear astrophysics, and fundamental symmetries. Over the past four years, many major upgrades were initiated, most of which are complete or nearing completion. These include the EBIS source for CARIBU, the intensity and efficiency upgrade, the 109 MHz cryostat energy upgrade, construction of AIRIS and AGFA, and the implementation of the Digital Gammasphere upgrade.

With these new capabilities already available or coming online, we are moving into a phase where we will be fully capitalizing on the investments made over the last several years while pursuing a handful of major upgrades. This will include obtaining optimal performance of the new equipment installed in the last few years, improving the reliability and efficiency of the facility operations, and ensuring that there is sufficient support for the new experimental equipment. New upgrades planned for this period are aimed at maximizing the physics capabilities of ATLAS while providing significant and unique capabilities that will complement the FRIB program.

The neutron generator for CARIBU will support an expanded physics program while improving reliability and reducing operating costs. The N=126 factory will provide access to a large range of neutron-rich nuclei which are presently inaccessible and not suited to beam production techniques at FRIB. The multi-user upgrade will allow us to better serve the low-energy user community by providing more beam hours, and enabling experiments that at present are considered too long to run. These upgrades will have a major impact on the ATLAS program, providing strong support for the user community during both early and full-power operation of FRIB.

The list of truly unique programs that the facility aims to carry out over the next 5-10 years, and that shape the strategic plan, spans the full range of the chart of nuclides. It includes the spectroscopy of the heaviest elements, which will be performed using the Gammasphere spectrometer coupled to the newly commissioned AGFA gas-filled spectrometer and the high-intensity stable beams of ATLAS. This region, above  $Z=102$ , is essentially unexplored by gamma-ray spectroscopy. New data will provide a key understanding of the stabilization of the nuclides on the predicted superheavy island of stability, and can only be fully explored with ATLAS and its instruments. In the heavy neutron-rich regions of the chart, the astrophysical r-process is the main process of interest, particularly since the spectacular observation of a neutron-star merger by the LIGO gravitational wave detector. The conditions in the astrophysical site of the r-process can be constrained by the nuclear physics properties of the nuclides involved in the production of the main abundance peaks. The CARIBU facility at ATLAS will continue providing input on the ever more exotic nuclei in the N=82 and rare-earth peak region, while the proposed N=126 factory will provide first access to the nuclides involved in the production of the last r-process abundance peak, the N=126 peak. This program will take advantage of the

unique high-intensity capabilities of ATLAS at the required 8-10 MeV/u energy regime and the ion manipulation technologies pioneered at ATLAS for CARIBU. This program is particularly timely given the progress in astronomical observations relevant to the r-process. For lighter nuclei, the main nuclear-structure goal for the coming decade is connecting the deep understanding of the lightest nuclides that can be described by *ab initio* calculations to the mid-mass nuclides that are now calculated by shell model techniques. This will require precision single-particle structure measurements spanning the nuclides a few nucleons away from stability from mass 20 up to nuclei in the region of the calcium and nickel isotopic chains. The high-quality single-particle structure information required can only be obtained in the 10 MeV/u energy regime with precision instruments such as HELIOS and the in-flight radioactive beams produced with the newly commissioned RAISOR separator (formerly known as AIRIS). These are but a few examples of flagship programs, critical to the low-energy nuclear physics mission and its user community, which can only be performed with ATLAS and its continuously expanding capabilities.

## **Introduction**

ATLAS is the DOE low-energy nuclear physics national user facility. It enables world-leading research at low energy and Coulomb-barrier energies by providing its users access to high-intensity stable beams, some unique radioactive beam capabilities, and state-of-the-art instruments. The capabilities of ATLAS are being continuously enhanced to better fulfill the evolving needs of its user community. This involves increasing the intensity of the available beams, providing access to new regions of the chart of nuclides, building new more sensitive detectors, increasing the number of hours the facility can deliver beam to users, or a combination of the above.

The ATLAS strategic plan provides a long-term path to guide the evolution of the facility by establishing a coherent plan for the accelerator, experimental equipment, and facility staffing that maximizes the return for the users. The plan starts with the identification of key scientific questions that the low-energy nuclear physics community is trying to address. This is done through community input and with guidance from the NSAC Long Range Plan for Nuclear Science. This defines flagship programs for the ATLAS user community that the facility should aim to enable and which might require new or improved capabilities. The common requirements are identified and this is used to set priorities for accelerator and experimental equipment developments.

The ATLAS user community and the Physics Division at Argonne National Laboratory have developed this strategic plan jointly. This plan is a public document, available to the entire ATLAS user community, and is updated as the need arises. A draft version of the 2018 ATLAS Strategic Plan was presented to the user community at a dedicated ATLAS Users Workshops during the Low-Energy Community Meeting held on August 10, 2018. ATLAS management and the users' executive committee then worked together to incorporate the outcome of this workshop into the final strategic plan. The draft plan was strongly endorsed by the community, which concluded the users meeting with the following unanimous resolution:

*“We strongly endorse the vision expressed in the draft ATLAS Strategic Plan for the future of the ATLAS facility and the proposed development of accelerator- and equipment-related initiatives that will enhance the scientific reach and efficient utilization of the ATLAS facility. These initiatives include the upgrade of ATLAS to provide **multi-user capabilities** which should be supported at a sufficient staffing level for its efficient operation.”*

## **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, in applications of nuclear 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 to address these goals. The current scientific goals are fully consistent with those defined in the NSAC 2015 Long Range Plan ([science.energy.gov/~media/np/nsac/pdf/2015LRP/2015\\_LRPNS\\_091815.pdf](http://science.energy.gov/~media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf)), the 2013 report to NSAC on Implementing the 2007 Long Range Plan ([science.energy.gov/~media/np/nsac/pdf/20130228/Tribble\\_NSAC-2013-tmp.pdf](http://science.energy.gov/~media/np/nsac/pdf/20130228/Tribble_NSAC-2013-tmp.pdf)), and the Performance Measures developed by NSAC for nuclear physics as updated in 2008 ([science.energy.gov/~media/np/nsac/pdf/docs/perfmeasevalfinal.pdf](http://science.energy.gov/~media/np/nsac/pdf/docs/perfmeasevalfinal.pdf)).

The optimization of the research program involves the following elements:

1. Effective long-term operation of the accelerator.
2. Effective support of the experimental program.
3. Capitalizing on the recent improvements to the facility and its suite of experimental equipment.
4. Development of new accelerator capabilities to enable new high-priority research opportunities.
5. Development of new experimental capabilities to pursue new high-priority research opportunities.
6. Nurturing the scientific and technical base of the low-energy research community 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.

The optimization of the strategic plan takes the following elements into account:

- ATLAS is the low-energy national user facility focusing on experiments with stable beams. The user community and ATLAS management acknowledge the inherent responsibility to make stable ion beams available to the national community.

- FRIB is a major priority for the nuclear science community, the ATLAS users and the Physics Division. The highest priority for low-energy nuclear science is to bring this facility on line. At the same time, the science and the community must be carefully nurtured through the optimized use of the steadily upgraded existing facilities.
- The priorities expressed in the NSAC Long Range Plan, the NSAC performance measures, and the scientific programs presented below, make it imperative that opportunities with unique radioactive beams at ATLAS continue to be pursued with high priority when identified as addressing important science by the community and being endorsed by the Program Advisory Committee.
- Beyond the commissioning phase of FRIB, ATLAS will address the needs of the low-energy community both as the only stable beam user facility and as a complement to FRIB in specific areas of rare isotope science.
- It is the view of the user community and of the management of ATLAS that a balance between the effective operation of ATLAS and the development of new accelerator capabilities and new instrumentation remains an essential consideration of the strategic plan. This approach helps realize the potential of the science for the low-energy community by continuously developing the long-term future of research at ATLAS.

### ***Major Scientific Programs:***

The major scientific goals below have been identified for the ATLAS research program. In each case, the anticipated experimental program for the next five to ten years is based on the ideas of the user community presented in the May 15-16, 2014, ATLAS Users Workshop (summarized in <http://www.phy.anl.gov/atlas/workshop14/index.html>), updated for recent progress and new developments and directions in the field as reflected in the 2015 Nuclear Physics Long Range Plan and subsequent Low Energy Community Meetings.

#### **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 goals were identified as most urgent by the ATLAS users:

- Comparisons of the properties of light nuclei ( $A < 20$ ) with *ab initio* calculations (Greens function Monte Carlo, no-core shell model) and other approaches;
- Study of the evolution of single-particle structure from light- to medium-mass nuclei, up to the  $Z=20$  closed proton shell nuclei region;
- 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;

- Study of 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 with particular emphasis on  $N=Z$  nuclei in the  $50 < A < 100$  region, and in the direct vicinity of doubly magic  $^{100}\text{Sn}$ ;
- The study of the structure of nuclei with  $Z > 100$  as a challenging test of theories describing the properties of the heaviest nuclei;
- The study of the properties of the nuclei at the highest spins and excitation energies. This includes (i) exploring the interplay between collective and single-particle degrees of freedom, (ii) searching for novel collective modes and their spectral signatures throughout the periodic table, and (iii) studying the dependence of level densities on angular momentum and temperature.

This program requires:

- Effective operation of ATLAS,
- Increased ATLAS beam intensities and energies,
- Increased beamtime availability from the planned ATLAS multi-user upgrade,
- Development of unique new radioactive beam capabilities, especially neutron-rich beams, with a reach as far as possible from the valley of stability with the neutron generator upgrade to CARIBU and with the planned  $N=126$  factory, and of intense exotic beams of higher energy and purity produced with the in-flight technique at the new RAISOR/AIRIS high-acceptance separator,
- Continued effective operation and improvement of Digital Gammasphere and its ancillary equipment,
- Targeted campaigns of research with GRETINA/GRETA,
- Continued development of the HELIOS spectrometer and its ancillary equipment,
- Continued improvement of the FMA focal plane instrumentation,
- Operation of the AGFA spectrometer for the detection of evaporation residues and products from more complex reactions,
- Expanded, dedicated low-background experimental area for low-energy CARIBU experiments and continued development of instrumentation for studies with CARIBU non-accelerated beams

## **II. Exploring the origin of the chemical elements and their role in shaping the reactions that occur in the high-temperature and explosive events of the cosmos**

The following scientific goals were identified as most urgent by the ATLAS users:

- Cross section measurements for reactions within the extended CNO cycle;
- Understanding the competition between  $(\alpha, p)$  and  $(p, \gamma)$  reactions along the rp-process path through measurements of the relevant cross sections;

- The measurement of reaction cross sections between heavy ions at energies relevant for star burning;
- The study of the reactions responsible for the p-process nuclei through dedicated techniques such as Accelerator Mass Spectrometry;
- Measurement of the mass and decay properties of neutron-rich nuclei close to the r-process path, especially around the N=82, rare-earth abundance peak, and N=126 waiting points;
- Development of the surrogate reaction technique for the determination of reaction yields along the s-, rp- and r-process paths.

This program requires:

- Effective operation of ATLAS and CARIBU,
- Increased ATLAS and CARIBU beam intensities,
- Increased beamtime availability from the planned ATLAS multi-user upgrade,
- Development of new rare isotope beam capabilities with the in-flight method combining higher intensities and higher energies (in some cases) with improved beam purity through the new RAISOR/AIRIS high-acceptance separator,
- Access to neutron-rich nuclei in the region responsible for the formation of the last r-process abundance peak through the proposed N=126 factory,
- Continued development of the HELIOS spectrometer and its ancillary equipment,
- Continued effective operation and improvement of Digital Gammasphere and GRETINA/GRETA,
- Continued development of instrumentation for studies with non-accelerated CARIBU beams in an expanded low-background experimental area.

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

The following scientific goals were identified as most urgent by the ATLAS users:

- The study of the hindrance of fusion at extreme sub-barrier energies, especially in systems of relevance for nuclear astrophysics;
- Understanding the impact of nuclear structure (deformation, shell structure, diffuseness, dissipation, etc.) on fusion, especially for reactions leading to  $Z > 100$  nuclei;
- Understanding the impact of neutron excess on nuclear reactions in the vicinity of the Coulomb barrier.

This program requires:

- Effective operation of ATLAS and CARIBU,

- Increased ATLAS intensities and increased beamtime availability from the planned ATLAS multi-user upgrade,
- Higher-intensity, higher-purity rare isotope beams produced with the in-flight method using the new RAISOR/AIRIS high-acceptance separator,
- Access to neutron-rich beams with the highest achievable intensities through the neutron-generator upgrade to CARIBU,
- Operation of the AGFA high-efficiency gas-filled spectrometer for the detection of evaporation residues and products from more complex reactions.

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

The following scientific goals were identified as most urgent by the ATLAS users:

- Searches for possible extensions of the Standard Model by improving by one order of magnitude or more the limits on scalar, tensor and right-handed components to the electro-weak interaction;
- Tests of the conserved vector current hypothesis and the unitarity of the first row of the Cabibbo-Kobayashi-Maskawa matrix from studies of beta decay;
- Studies of the antineutrino spectra in abundant fission products to determine the origin of the apparent reactor antineutrino anomaly observed in neutrino oscillation experiments.

This program requires:

- Effective operation of ATLAS,
- Increased ATLAS intensities and increased beamtime availability from the planned ATLAS multi-user upgrade,
- Expanded low-background low-energy experimental area at CARIBU.

#### **V. Nuclear physics applications at ATLAS and CARIBU**

While the ATLAS capabilities can contribute to the development of various applications outside the scope of its core mission, some of these potential applications have sufficient overlap to its main science mission to be included here. The following scientific goals related to applications have been identified as most urgent by the ATLAS users:

- The study via Accelerator Mass Spectrometry (AMS) of neutron-capture cross sections on various isotopes of interest for reactor physics and nuclear astrophysics;
- The study of the decay properties of neutron-rich isotopes (gamma, beta, beta-delayed neutrons) of importance for accurate modeling of kinetics and decay heat in novel nuclear fuel cycles and for stockpile stewardship;

- Studies via heavy-ion bombardment of damage in materials considered for advanced reactors and of modifications to superconducting materials;
- The development of new production techniques for specific isotopes for medical and stockpile-stewardship applications.

This program requires:

- Effective operation of ATLAS, including improved control techniques for accurate configuration scaling and reproduction of previous accelerator configurations,
- Increased ATLAS beam intensities and energies,
- Increased availability of beamtime through the proposed ATLAS multi-user upgrade,
- Access to neutron-rich beams with the highest achievable intensities through the neutron-generator upgrade to CARIBU,
- Expanded, dedicated low-background experimental area for low-energy CARIBU experiments,
- Availability of dedicated experimental stations at ATLAS.

## *Initiatives:*

Based on the program requirements laid out above, a number of initiatives have been identified to carry out this research program. They vary in scope from the full utilization of recently commissioned new experimental systems, to the completion of ongoing upgrades recently initiated, to the design, construction and installation of new state-of-the-art capabilities. The main initiatives, ordered roughly by their time of implementation, are listed below:

- Improve the ability of ATLAS to deliver high-intensity, high-purity rare isotope beams produced by the in-flight technique by completing the RAISOR/AIRIS high-acceptance separator and developing production targets able to tolerate the highest primary beam intensities;
- Complete the instrumentation of the AGFA high-efficiency gas-filled spectrometer for the detection of reaction products from fusion-evaporation and from complex reactions;
- Complete the installation of a large low-background area for experimentation with low-energy CARIBU beams;
- Complete the full instrumentation of HELIOS, and continue the development of ancillary detectors;
- Expand the range of unstable, neutron-rich beams available from ATLAS with the CARIBU upgrade by increasing the efficiency for charge breeding and the purity of the reaccelerated beams using the newly completed EBIS charge breeder, and implementing the proposed neutron generator upgrade to CARIBU;
- Provide first access to exotic nuclei south and east of the  $^{208}\text{Pb}$  on the chart of nuclei through the completion of the proposed N=126 factory;
- Move forward with the development and implementation of the ATLAS multi-user upgrade to allow ATLAS to address the present large oversubscription of the facility by providing a larger fraction of the number of research hours requested by its user community;
- Extend the energy range of ATLAS for high-intensity stable beams, primarily for in-flight production of exotic beams with RAISOR/AIRIS and the N=126 factory;
- Maintain and improve the instruments present at ATLAS (Digital Gammasphere, FMA, ion and atom traps, magnetic spectrometers) to increase count rate capabilities and maintain their state-of-the-art status;
- Develop high-efficiency detection systems for the low-energy area of CARIBU, i.e., instrumentation for beta-decay studies, laser spectroscopy, etc.;
- Maintain an infrastructure capable of developing or adapting other detectors designed by the community for use at ATLAS. This includes maintaining capabilities to couple devices with older data acquisition systems to the upgraded digital electronics acquisition devices operational at ATLAS.

## ***Approach:***

An approach based on a coherent program of accelerator and experimental equipment upgrades was initiated to implement the recommendations of the 2014 ATLAS long-range plan. The physics motivating the 2018 ATLAS long-range plan is the logical continuation of the previous efforts, building on the physics results and technical developments since then. The plan to accomplish these goals relies on a joint accelerator/experiment upgrade program that includes a realistic timeline and appropriate staffing levels. It builds on the full utilization of the recently completed upgrades and on the strategic addition of further upgrades providing unique capabilities enabling the flagship programs identified in the previous sections. The main components of this approach, starting with the items that were implemented as part of the previous long-range plan, are given below.

### (a) Accelerator:

#### a.1) Recent Accelerator Upgrades

A number of major upgrades have either been initiated or completed in the last four years to implement the recommendations of the 2014 ATLAS long-range plan:

- The EBIS charge breeder was designed, built, and commissioned for the CARIBU facility. This upgrade removes the contamination from stable isotopes that accompanied most reaccelerated CARIBU beams. This upgrade now allows the reaccelerated CARIBU beams to be used in experiments that detect beam particles at zero degrees, such as active target experiments or HELIOS, which could not operate at their full potential with the previous contamination. The EBIS charge breeder is now operational and, in addition to providing essentially pure radioactive beams, it has also increased the efficiency of the charge breeding process. An additional benefit is that the full-intensity radioactive beam is now delivered in short macro pulses with the CW ATLAS linac available between pulses, enabling the future multi-user upgrade.
- The ATLAS intensity and efficiency upgrade was completed and fully commissioned. This upgrade, with the addition of a normal conducting CW RFQ at the front end of the machine and a new superconducting cryostat with seven quarter-wave resonators, improved the reliability of the accelerator while allowing the acceleration of higher intensity stable beams, increasing the transport efficiency of the reaccelerated CARIBU beams, and making space available in the ATLAS tunnel for the RAISOR/AIRIS separator.
- The RAISOR/AIRIS separator was designed, built, installed, and has recently met its commissioning goals. RAISOR will increase the intensity and purity of in-flight-produced light radioactive ion beams while allowing these beams to be delivered to most experimental stations at ATLAS.
- A major upgrade of the last ATLAS cryostat, the so-called 109 MHz cryostat, was started. This upgrade will increase the total energy that can be provided by ATLAS,

enabling the production of in-flight beams either with higher energy or with reactions of larger negative Q-value.

- The tandem was retired and moved to the end of the tandem hall to make space for a new low-background low-energy experimental area for CARIBU.

#### a.2) Planned Operation and Upgrades of ATLAS for the Next Five Years

Addressing the high-priority physics programs highlighted in the present ATLAS long-range plan will require ATLAS to operate reliably while taking full advantage of the improved capabilities of the facility brought about by the upgrades initiated in the last four years. In addition, new capabilities that build on these recent upgrades are necessary to allow the ATLAS user community to fully reach the stated physics goals. The main accelerator-related activities for the coming five years will focus on:

- Improving the ability to reliably, efficiently, and safely operate the increasingly complex ATLAS facility with increased intensities of stable and radioactive beams. This will involve upgrades of the radiation interlock system of ATLAS, beam diagnostics and control system.
- Completing the full removal of the tandem and the installation of beamlines and services to the target stations that will host permanent and visiting experimental setups in the new low-energy CARIBU experimental area. The larger experimental area will allow for the full development of the decay spectroscopy program for neutron-rich isotopes while the two orders of magnitude lower background levels will significantly increase the sensitivity of decay experiments.
- Completion of the upgrade to the 109 MHz cryostat to increase the maximum beam energy available at ATLAS, enabling the use of larger negative Q-value reactions for production of in-flight radioactive beams with RAISOR/AIRIS.
- Installation of a new high-intensity ECR source for stable beam delivery at ATLAS. A superconducting ECR source is needed to take full advantage of the ability of ATLAS to now accelerate up to 10  $\mu\text{A}$  of heavy ions. These high beam currents will be critical to high-visibility programs such as the spectroscopy of the heaviest isotopes with  $Z > 100$  at AGFA, the production of intense mid-mass radioactive beams with RAISOR/AIRIS, and the  $N=126$  factory.
- Construction and installation of the neutron-generator upgrade to CARIBU. The neutron generator will provide a more reliable and reproducible source of neutron-rich isotopes via the neutron-induced fission of actinides in a thin foil. This upgrade will replace the thin  $^{252}\text{Cf}$  source, which has proven difficult to procure, with a more intense source for these neutron-rich isotopes. It also offers a more advantageous fragment distribution around the important  $^{132}\text{Sn}$  region.
- Construction of a multi-user upgrade of ATLAS, building on the recently completed Intensity and Efficiency upgrade of ATLAS which enables the high-efficiency acceleration of stable beams to much higher intensity ( $>10 \mu\text{A}$ ), and takes advantage of the newly-installed EBIS charge breeder. The shift to the EBIS charge breeder has essentially eliminated the stable beam contaminants that accompanied the reaccelerated CARIBU beams. It also resulted in a significant change in the delivery of reaccelerated CARIBU beams as the full radioactive beam intensity is now compressed into short macro pulses taking up less than 1% of the

total time available for acceleration. The ATLAS multi-user upgrade will enable the simultaneous acceleration of a CARIBU beam and a stable beam by fully exploiting the availability of the linac during the remaining 99% of the total time. It is estimated that this upgrade would result in an increase of 2000-3000 hours in the total number of experimental hours the facility can deliver to experiments. In so doing, this initiative addresses part of the large current oversubscription of ATLAS while also enabling longer duration experiment required for studies with small cross sections or with low-intensity radioactive beams.

### a.3) Planned Upgrades of ATLAS for the 5-10 Year Period

The plan for the ongoing and proposed upgrades of ATLAS in the next five years is well defined since this time period is required to put in place the capabilities needed to address the already identified physics goals. The 5-10 year period will see the completion of these proposed measurements, taking particular advantage of the multi-user upgrade to provide the required beamtime for the long-measurement campaigns. It will also see the implementation of the changes to the facility required to address the key questions that will emerge from the results obtained at ATLAS and other facilities such as the first series of experiments at FRIB. While the exact nature of these questions is still unknown, the uniqueness of ATLAS will rest, in part, in the ability to access the very heavy region that will not be readily accessible at FRIB. Remaining at the forefront in this region will require higher intensity beams of very heavy nuclei. This can be accomplished by the addition of a new cryostat to replace all remaining split-ring cavities at ATLAS with the latest technology quarter-wave cavities used in recent ATLAS upgrades. The maximum beam intensity at ATLAS would then exceed 10  $\mu\text{A}$  at 10 MeV/u, limited solely by ion source performance and shielding.

### (b) Instrumentation:

#### b.1) Recent Instrumentation Upgrades

Several on-going instrumentation projects, initiated by the user community and the ATLAS scientific staff, were completed in the last four years to take full advantage of the present and forthcoming accelerator upgrades. These include:

- Design, construction and commissioning of the AGFA high-efficiency gas-filled spectrometer for products of fusion-evaporation and complex reactions. This device, built to maximize gamma-recoil coincidence efficiency, will be critical for the spectroscopy program on  $Z > 100$  isotopes;
- Completion of the instrumentation for the RAISOR/AIRIS large-acceptance separator to increase the intensity and purity of in-flight radioactive beams produced at ATLAS;
- Completion of the instrumentation for HELIOS with the addition of an optimized light-ion detector for higher coverage in both the forward and backward hemispheres and continued development of ancillary detectors and target systems as required for approved experiments;

- Installation and commissioning of a Multi-Reflection-Time-of-Flight (MRTOF) spectrometer to further purify CARIBU beams;
- Modification of the FMA entrance quadrupole to increase the efficiency when operating with GRETINA;
- Continuous improvements to Digital Gammasphere, the FMA focal plane detectors, the CPT/BPT, the MUSIC detector, the X-array and other existing permanent instruments at ATLAS as needed to maintain their state-of-the-art status.

#### b.2) Planned Upgrades to the ATLAS Experimental Equipment for the Next Five Years

Addressing the proposed physics programs highlighted in the current long-range plan requires new experimental equipment that either builds on the new accelerator capabilities that are being implemented or goes beyond the experimental capabilities that were envisaged in the previous ATLAS long-range plan. The main proposed experimental developments are:

- Construction of the N=126 factory to provide access to the exotic nuclei south and east of  $^{208}\text{Pb}$  on the nuclear chart. This facility will provide unique access to the unexplored region responsible for the formation of the last abundance peak in the r-process. It builds on the very high intensities available at ATLAS for heavy ions at energies of 8-10 MeV/u and the unique expertise in high-intensity gas catcher and ion manipulation techniques developed at ATLAS;
- Development of a laser spectroscopy capability for the CARIBU low-energy beam area. This instrumentation will take advantage of the unique low-energy beams available at CARIBU to obtain information on the shape and spin of very neutron-rich isotopes;
- Construction and installation of a new RF trap system for the detection of beta-delayed neutron emission using the recoil detection technique;
- Construction and installation of a new beta spectrometer at CARIBU, based on cyclotron radiation detection, to measure the beta spectrum of very neutron-rich isotopes, relevant to the reactor antineutrino anomaly;

#### b.3) Planned Upgrades to the ATLAS Experimental Equipment for the 5-10 Year Period

The timescale for development and installation of experimental equipment of the scale used at ATLAS is typically three to four years. The plan for the ongoing and proposed upgrades to the ATLAS experimental equipment in the next five years is, therefore, already fairly well defined. The 5-10 year period will see the measurements proposed for the new instruments currently under construction being performed. The key questions that will emerge from the results obtained at ATLAS and other facilities, such as the first series of experiments at FRIB, will determine some of the new requirements for experimental equipment. It is difficult to extrapolate what the best technology to address these yet-unknown requirements will be. There are, however, important open questions that cannot be answered experimentally now but which could be answered in the future by building on the technology that will be uniquely available at ATLAS five years from now. A high-profile example is the fissionability of the very neutron-rich heavy isotopes at the termination of the r-process which is critical to understanding the fission recycling

expected in environments with high neutron-to-seed ratio. The ability of the N=126 factory to produce isotopes in this region, coupled to the multi-user upgrade, would allow production of these isotopes during 99% of the rf duty cycle, while they are injected and charge bred in the EBIS for post-acceleration during the remaining 1% of the duty cycle. This would provide the first Coulomb barrier beams in this region that could be used to determine the fissionability of isotopes in this critical region.

It is also the view of the user community and of the management of ATLAS that the development of new instrumentation in the 5-10 year timescale should be viewed in the context of the development of FRIB. ATLAS is the accelerator of choice for the low-energy nuclear physics community to test new concepts and ideas in preparation of the FRIB experimental program with low-energy and reaccelerated beams. Furthermore, future sharing of experimental equipment between FRIB and ATLAS is viewed as a strong possibility. Hence, the list above is likely to change and evolve.

In the past, the user community has expressed its concerns about the availability of target fabrication capabilities sufficient, not only for the ATLAS program, but also for research at other national and university-based facilities. It strongly supports the Center for Accelerator Target Science (CATS) recently established by the Physics Division, and we believe that the recent addition of one FTE to this group will allow CATS to address these concerns going forward.

## *Timeline for implementation and personnel needs:*

### Timeline:

The ATLAS Strategic Plan presents a path forward for ATLAS to efficiently fulfill the needs of its user community. The major accelerator and experimental equipment upgrades are laid out on a logical timeline where new upgrades build upon previous upgrades, while allowing construction and installation with the workforce and resources available. The proposed timeline also ensures that new programs are continuously enabled and that the new upgrades are implemented with minimal impact on the operations schedule. Two tables highlighting the timeline for the installation of the main accelerator and equipment upgrades are shown below.

TIMELINE FOR ATLAS ACCELERATOR UPGRADES	Design/preparation		Construction/Installation				Operation								
	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027	FY2028
Project															
ATLAS Intensity and Efficiency upgrade															
ATLAS 109 MHz cryostat upgrade															
EBIS charge state breeder															
Radioactive beam diagnostics															
ECR3 ion source (14C, 225Ra, ...)															
New low-energy experimental area for CARIBU															
Neutron-generator for CARIBU															
High Current ECR Source															
ATLAS Multi-user Upgrade															
Reaccelerating N=126 factory beams															
Add one cryostat replacing final split-ring cryostats															

TIMELINE FOR ATLAS EQUIPMENT UPGRADES	Design/preparation		Construction/Installation				Operation								
	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024	FY2025	FY2026	FY2027	FY2028
Project															
Digital upgrade to Gammasphere and FMA															
AGFA gas filled spectrometer															
AIRIS in-flight spectrometer															
N=126 factory															
GRETINA/GRETA campaigns															
Beam tracking in HELIOS															
Laser spectroscopy at CARIBU															
$\beta$ - $\gamma$ -n spectroscopy in low-E CARIBU area															
Refurbishing Gammasphere															
Exp. equip. for reaccel. N=126 factory beams															

Staffing requirements for near-term (single-user) operations:

ATLAS operates at a very lean staffing level. The facility has run over the last several years with only seven operators to run the facility 24/7, and the various support subgroups (ion source, cryogenics, electronics, control system, mechanical/vacuum) had only two members each. This was considered the minimum staffing level required to achieve the typical 5000-6000 hours of ATLAS operations per year. These staffing levels require compromises such as having two operators on shifts for only about half of the shifts and single coverage (with the experimental group providing a safety watch) for the remaining shifts and limiting beam changes during the weekend. These adjustments allow 24/7 beam delivery, but with reduced flexibility and increased susceptibility to sick leaves, vacations, and unexpected retirements or departures of key personnel.

Many of these issues have been addressed in FY18 with the addition of one operator, one control engineer and the posting of a position for a cryogenics engineer. This will provide better operator coverage as well as increased support for operation of the facility, required to make full use of several recent upgrades. In addition, a postdoc has been added to the target group to strengthen the group and to ensure future expertise in target making.

Staffing requirements to support the multi-user upgrade:

The proposed multi-user upgrade to ATLAS will result in the simultaneous operation of two sources and two experimental stations for roughly half of the operating time. Accelerating two simultaneous beams will also add to the complexity of the accelerator tuning procedures as well as increase the effort required to set up experimental equipment for a greater number of experiments.

This added complexity cannot be accommodated at the current staffing level and will require the addition of one FTE to the ion source group and one operator to the accelerator staff. This is the minimal staffing level required to operate the facility in multi-user mode. To ensure smooth operation and provide optimal support for operation and experimental setup, we propose the addition of one mechanical/utilities FTE to the ATLAS staff, and a mechanical engineer and technician to the physics support group to help users set up two experiments at the same time. This will also help relieve some of the additional workload that running multiple experiments simultaneously will put on the Ph.D. staff responsible for the various instruments, enabling them to focus on achieving optimal performance from the new equipment while continuing to contribute to the development and implementation of future upgrades.

## **Appendix A: 10-year staffing plan**

The strategic plan for ATLAS will maintain it as the flagship stable beam facility worldwide in the coming decade. It proposes a number of ambitious new developments for the facility that will provide access to unexplored regions of the chart of nuclides and significantly increase the available beamtime to its users. This will come at the cost of increasingly complex experiments, beam setup, and the requirement to install and maintain two experiments running simultaneously once the multi-user upgrade is in operation. This staffing plan addresses the need for additional workforce to optimize the short-term operation and eventually the multi-user operation of this more complex facility safely and efficiently. The information is presented in two tables, one for ATLAS operation and one for ATLAS Experimental Support.

The ATLAS Operations group ensures the safe and efficient operation of the ATLAS accelerator. The group is composed of operators, which handle the day-to-day operation of the facility, and the support groups, which maintain the various critical accelerator subsystems (cryogenics, electronics, ion sources, control system, vacuum, ...). The added complexity of the machine with the addition of AIRIS, CARIBU and its EBIS source, the increase in the number of runs requiring very high beam intensity, and soon, the multi-user upgrade, put higher demands on the operating staff. The proposed staffing plan, shown in table A.1 below, addresses this increased workload while also reducing vulnerability to loss of key personnel.

The funding level of FY18 allowed ATLAS to start this process. Five key hires were identified as required to reach the operating staff level needed for the operation of the ATLAS multi-user upgrade starting in FY21-22. One cryogenics staff to help improve the reliability and maximum capacity of this subsystem, one control person to improve the automation of the facility which will be critical for multi-user operation, one ion source person to deal with having to run multiple sources simultaneously, and two additional operators to have two operators on duty for a larger fraction of the shifts. These essential increases in workforce are handled within a constant effort budget starting with the FY18 budget level. As shown in the table, this approach is being implemented with an additional control engineer and an operator hired in FY18, the cryogenic position posted in FY18 and expected to be filled in FY19, an additional position in the ion source group aimed to be filled in FY20 and a second additional operator position aimed to be filled in FY21. The table also shows part of an additional FTE in FY18 for the CATS target making group (which is paid mostly out of Experimental Support) and the removal of the ES&H partial FTE that is now accounted for out of overhead after a realignment of this group within ANL. All of these changes bring the ATLAS Operations group to what is considered as the required minimal staffing level for safe and efficient operation in the multi-user mode. The table also shows the addition of one mechanical/utilities FTE in FY21 to help handling the additional demands coming from setting up multiple beamlines and experiments simultaneously once the multi-user upgrade starts operating. This is deemed important to bring operation staffing to a healthy level in the multi-user regime. This last additional hire would require an increase of \$400k above the constant effort budget level starting in FY21.

ATLAS Ops	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28
Admin/Sec	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
CARIBU	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Controls	2.5	2.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Co-op	0.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Cryogenics	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Electronics	2.4	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Engineer	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ES&H	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ion Sources	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mech/Util	2.3	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Operator	6.7	7.3	8.0	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Management	2.2	2.7	2.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Target Lab	0.2	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
OT Operator/ Mech/ Cryo	1.3	1.0	1.0	1.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Grand Total	25.8	27.4	30.3	31.1	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7

*Table A.1: 10-year staffing plan for the ATLAS Operations group showing FTEs per category. The changes discussed in the text are highlighted in color (green indicates additions that require funding increases beyond constant effort).*

The ATLAS Experimental Support group develops and maintains the experimental equipment and supports users performing experiments at ATLAS. The 10-year staffing plan for this group is shown in table A.2 below. The group has gone through significant changes in FY18 with the realignment of the electronics group (previously partly contracted from HEP), the retirement of two mechanical engineers, and the loss of one detector specialist. This group also has to handle a higher workload with the new equipment recently commissioned and the coming running of more experiments per year once operation of the ATLAS multi-user upgrade starts in FY21-22. In FY18, the electronics group was rearranged and a mechanical engineer and an electronics engineer replaced the two retiring mechanical engineers. The lost detector specialist will be replaced in FY19. We propose to hire an additional mechanical engineer in FY19 to improve the facility's ability to implement the upgrades and to install new equipment. In FY21, with the start of operation of the multi-user upgrade, one additional mechanical/utilities technician will be required to help set up multiple experiments at the same time. The addition of these two FTEs will require an increase of \$600k in the funding above the constant effort budget starting in FY21.

ATLAS Experiment Support	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28
Admin/Sec	2.4	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Comp/DAQ	1.9	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Co-op	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Detector Specialist	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Electronics	0.5	1.8	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
ES&H	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mech Eng.	1.4	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Mech/Util	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ph.D Staff	4.1	3.8	4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Supervision	0.6	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Target Lab	0.8	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
User Liaison	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Grand Total	14.8	13.8	15.4	15.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1

*Table A.2: 10-year staffing plan for the ATLAS Experimental Support group showing FTEs per category. The changes discussed in the text are highlighted in color (green indicates additions that require funding increases beyond constant effort).*

## **Appendix B: Additional ATLAS contributions to the DOE mission**

ATLAS is a critical component of the DOE Nuclear Physics portfolio. While the main mission of ATLAS is basic nuclear science, the ATLAS facility and the expertise of its staff also contribute to other aspects of the DOE mission. Some of these contributions are highlighted below.

- The Center for Accelerator Target Science (CATS) is a national facility based on the existing target development laboratory at Argonne National Laboratory. The most important and primary goal to the CATS mission is support of the ATLAS Scientific Program: supplying experimental targets, foils, windows, sources and isotopic material for beam production. It also serves the US and international low-energy community by producing targets for other facilities when possible, training individual investigators and students in target making, carrying out R&D activities, and developing a library of existing targets that will serve as a pool available to the whole community. The head of CATS also serves as chair of the FRIB Users Organization Target Working Group, and CATS will provide thin targets for use at ReA and FRIB.
- The Accelerator R&D group, centered at and supported in part by ATLAS, has developed world-leading expertise in superconducting cavity development, fabrication, and processing. This NP-developed expertise is critical to, and has been made available to, a number of facilities within the NP, HEP and BES programs. Examples include major contributions to the FNAL Proton Improvement Project and the Advanced Photon Source Upgrade. These efforts benefit from collaboration with accelerator R&D groups in High Energy Physics, Nuclear Engineering, and at the Advanced Photon Source (APS) at Argonne.
- Experimental and facility equipment developed at ATLAS such as the gas catcher technology and the HELIOS spectrometer are being exported to a number of facilities worldwide (gas catcher at Berkeley, SOLARIS for FRIB) where they enable new physics research that was not possible before.
- The ATLAS facility, with its ability to produce essentially any stable beam, is ideally suited to R&D on new techniques for the production of medical isotopes, material irradiation, new detector technology characterization, and various other applications of nuclear science and accelerator technology. A significant program of R&D on isotope production is enabled by the laboratory's expertise in nuclear and radiochemistry, while other programs are strengthened by collaboration with Nuclear Engineering and the detector R&D groups in HEP and at the APS.
- The CARIBU upgrade to ATLAS provides unique access to mass-separated neutron-rich isotopes that play a critical role in our understanding of stockpile stewardship, reactor decay heat, and a number of other societal applications.

While we prioritize the support of the ATLAS program, these groups are able to make their unique expertise available to support other high-impact NP and Office of Science programs, with project funding coming from the associated programs.