SUPERCONDUCTING RF ACTIVITIES AT ARGONNE NATIONAL LABORATORY

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Abstract

SRF activities at Argonne National Laboratory include the continued operation of ATLAS (Argonne Tandem Linac Accelerating System), the first superconducting heavy-ion linac, in operation since 1978. A strong program in SRF R&D continues to the present where efforts are focused on the Rare Isotope Accelerator (RIA) project. RIA development involves two major sections of linac, a superconducting multi-ion multi-charge-state driver spanning nearly the entire range of particle velocities, $0.02<\beta<0.84$, and a superconducting RIB (Radioactive Ion Beam) post accelerator for multi-charge-state rare isotopes. ANL is expanding its infrastructure needed to develop and process new types of superconducting cavities for RIA. In addition, interest is developing at Argonne's Advanced Photon Source in the application of SRF technology to a proposed 4th generation light source.

1 INTRODUCTION

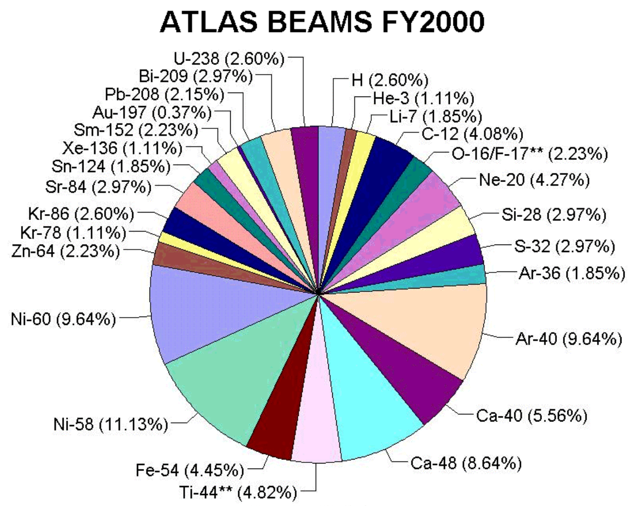
Sections of the superconducting (SC) ATLAS accelerator have been operating for over 23 years and continue in full operation today. A detailed discussion of ATLAS was given previously [1]. This paper updates the operational characteristics and gives an overview of related development. In the past decade R&D efforts have been and continue to be focused on RIA [2], the next generation radioactive ion beam facility. A RIA driver linac in CW operation will accelerate multiple charge state ions ranging in mass from protons up to uranium with energies up to 900 MeV for protons (400 keV/u for uranium) and a beam power of 400 kW. A second SC linac, the Radioactive Ion Beam (RIB) linac necessary for the efficient acceleration of rare isotopes has also been designed at ANL.

Development of drift-tube cavities for the RIA driver linac for velocities $0.02<\beta<0.6$ is being performed at Argonne. Until recently relatively little work had been done for ion linacs over much of this velocity region. Recently a pair of prototype spoke cavities with β=0.3 and 0.4 have been successfully tested. Surface preparation for RIA prototype cavities is being performed at ANL using new high-pressure rinse and chemical polish facilities.

2 ATLAS OPERATIONS

2.1 Facility Overview and Update

ATLAS continues to operate as a national user facility for heavy-ion nuclear and atomic physics research. It provides high quality beams of ions spanning nearly the entire mass range from protons to Uranium for 5000+ hours per year (see *e.g.* Figure 1). The operating staff is comprised of 23 persons.



Operating Statistics

Machine Operation	FY1994	FY1995	FY1996	FY1997	FY1998	FY1999	FY2000
Scheduled Research Hours	5808	5088	6216	5628	5622	6096	5496
Research Hours (on Target)	5198	4542	5730	5126	5628	5998	5384
Accelerator Devel. Hours	75	47	96	243	121	48	76
Total R & D Hours	**5273**	**4589**	**5826**	**5369**	**5749**	**6046**	**5460**
Scheduled Maintenance	613	716	469	622	460	300	597
Experimental Downtime	594	536	489	498	409	440	296
Operating Reliability (%)	83.9	89.5	92.2	91.5	93.4	93.2	94.9
Num. of Experiments	63	52	66	51	53	56	51

Figure 1: Beams delivered at Argonne's ATLAS facility for fiscal year 2000. Approximately 7% of the beams delivered were rare isotopes.

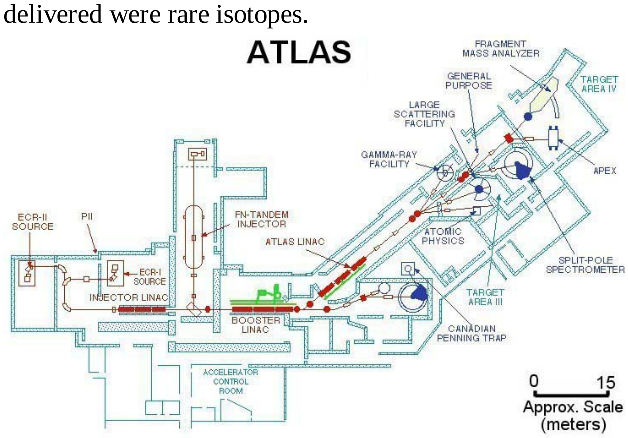


Figure 2: Top view of the ATLAS facility containing three major sections of superconducting LINAC.

The facility consists of three sections of SC linac as shown in Figure 2. The Positive-Ion Injector (PII) contains 18 4-gap niobium quarter wave cavities covering

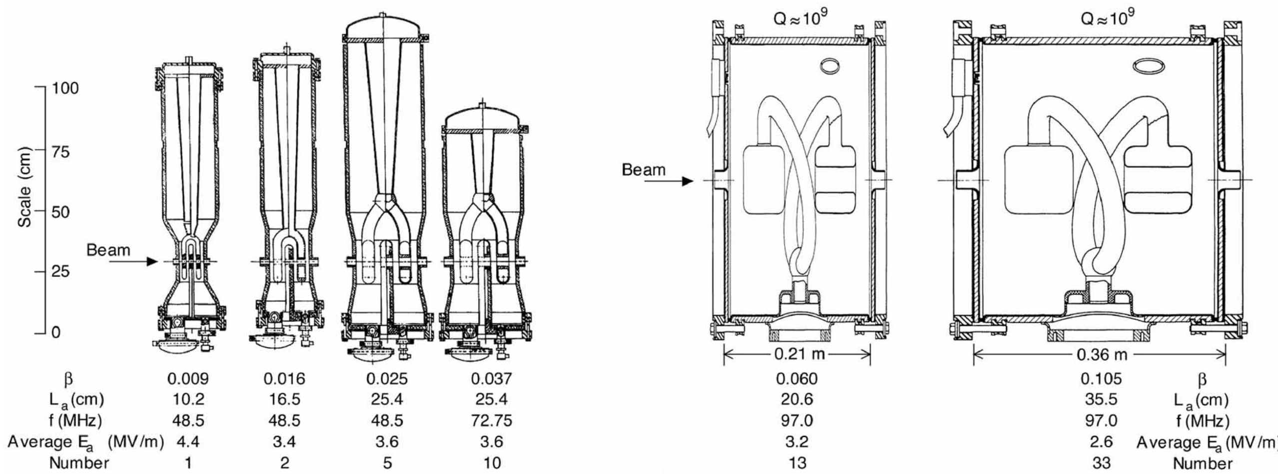


Figure 3: Cutaway view of the quarter wave resonators used in the Positive Ion Injector (left) and the split-ring resonators used in the 'booster' and 'ATLAS' sections of the accelerator.

the velocity region $0.009 \leq \beta \leq 0.037$. The 'Booster' and 'ATLAS' sections are comprised of 24 and 18 resonators each, optimized respectively for β=0.06 and β=0.105. All SC resonators are pure niobium with explosively bonded copper/niobium housings. Cross-sectional views of each cavity type are shown in Figure 3. Together, the ATLAS resonators have logged over 3 million hours of operating time.

2.2 ATLAS Upgrades

Improved phase stability of ANL cavities, particularly for the large, low-β structures with low lying acoustic modes, continues to be an area of interest. The ATLAS staff has designed and implemented vibration dampers for three of the PII resonators based on a similar damper design from Legnaro [3]. Several months of online operation indicate that the ANL dampers have reduced typical vibration induced frequency excursions by approximately a factor of five. An example for a β=0.016 resonator in the Positive Ion Injector linac is indicated in Figure 4. Today the contribution to research time lost due to cavity vibrations is negligible. Additional benefits include a reduced demand on the electronic fast tuner system and a reduction in the phase wobble of transmitted beams.

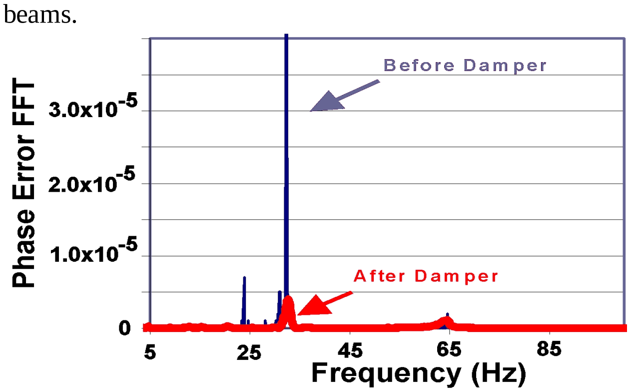


Figure 4: Phase error for a β=0.016 resonator before and after installation of a vibration damper.

In an effort to increase the operating fields in existing ATLAS resonators, six β=0.105 split–ring cavities are being processed in a new high-pressure rinse facility. The excellent performance resulting from high-pressure rinse for the first rinsed 17-year-old ATLAS split-ring are presented in Section 4.

3 R&D RELATED TO RIA

3.1 A RIA Driver Linac

A driver linac for RIA shown in Figure 5 at the ANL site has been designed based superconducting rf cavities and will produce high-power (≥400 kW) cw beams over nearly the entire mass range from protons to uranium [4]. Such a driver is necessary to produce the widest array of and most intense beams of nuclei far from the valley of stability.

A novel design feature is the planned use of multiple charge-state beams [5] possible with the large acceptance and strong focusing provided by independently phased superconducting rf cavities. The use of multiple charge states will lead to a factor of eight increase in available beam power. A proof of the concept including experimental measurements with multiple charge states of uranium has been performed at ATLAS [6].

Cavity development for the driver has been a focus of SRF activities at ANL. Approximately eight types of cavities are needed to span the required velocity range $0.02<\beta<1.0$. Drift tube structures suitable for acceleration of ions with velocities $0.02 \leq \beta \leq 0.6$ are being developed at ANL [7,8]. Detailed simulations of the mechanical and rf properties for a double-cell β=0.4 spoke cavity were recently reported by Shepard et al. [9]. Five other cavity types including two low-β 4-gap fork structures, two dual-gap quarter-wave structures and a half-wave resonator have been designed and are shown in the inset in Figure 5.

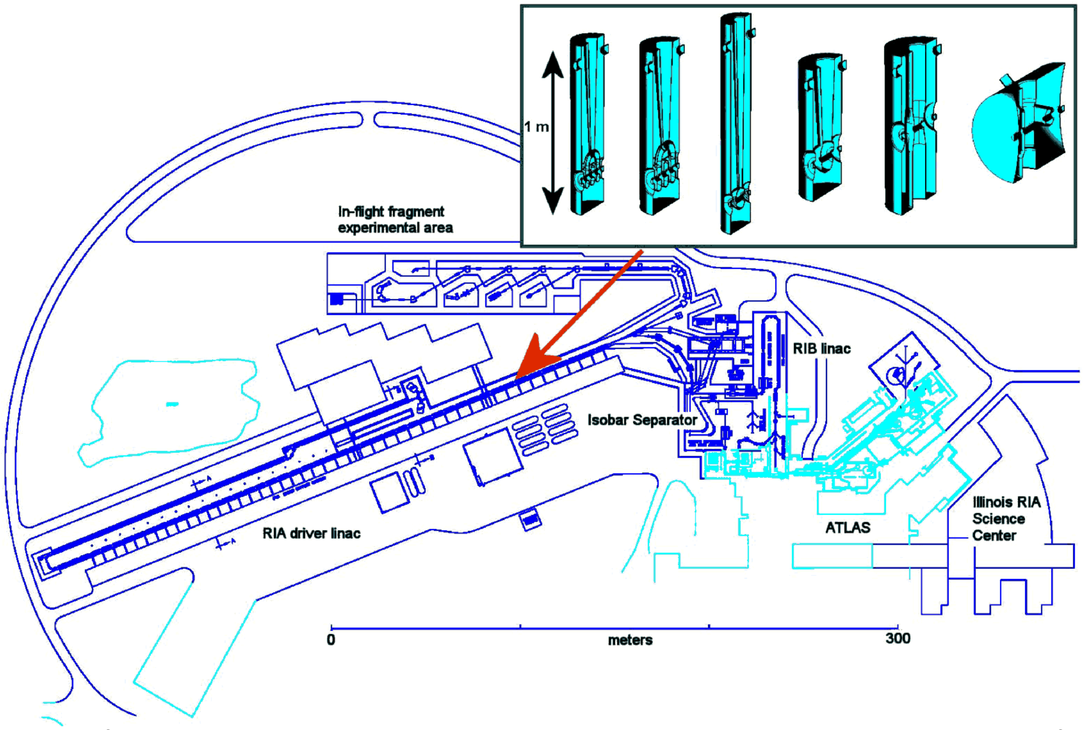


Figure 5: Layout for the Rare Isotope Accelerator at Argonne National Laboratory. The inset shows a set of niobium drift-tube cavities suitable for 0.02<β<0.6 for the RIA driver linac.

3.2 RIB Linac

The RIA facility requires a post accelerator or Radioactive Ion Beam (RIB) linac to produce high-quality beams of rare isotopes with high transmission efficiency. The RIB linac must accept ions over the entire mass range in charge state 1+ at least initially. The design of Ostroumov et al. [10], based on superconducting rf cavities provides the basis for all but a small portion the system as shown in Figure 6.

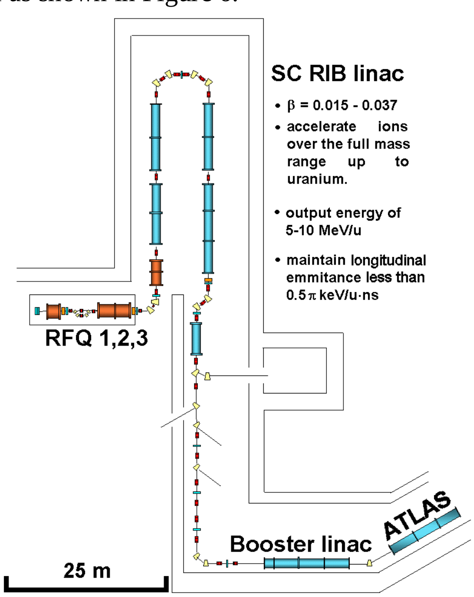


Figure 6: Design for a post accelerator for the Rare Isotope Facility based largely on superconducting rf quarter-wave cavities.

3.3 Hardware development

A 350 MHz β=0.4 spoke cavity prototype for RIA with a design accelerating gradient of 5 MV/m, shown in Figure 7, has been successfully tested at ANL [11]. After surface reprocessing using new buffered chemical polish (BCP), high-pressure rinse (HPR) and high-power (5 kW) rf conditioning facilities, accelerating fields of 7 MV/m were achieved at T=4.3 K and 10 Watts input rf power as indicated in Figure 8.

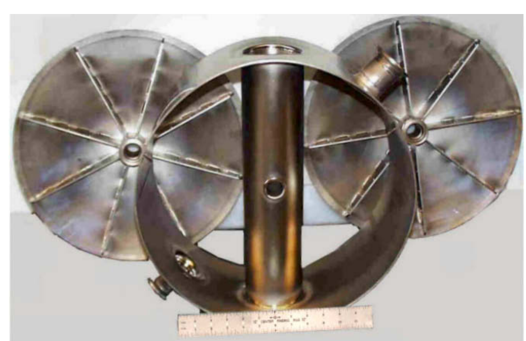


Figure 7: A 350 MHz β=0.4 prototype spoke cavity prior to welding on the end plates.

A niobium bellows slow tuner has been developed and tested at ANL as part of the New Delhi 97 MHz quarter-wave resonator project. However, a similar design should be entirely suitable for use on the low-β quarter-wave resonators required for RIA. The bellows shown in Figure 9 was mounted on a 97 MHz quarter wave resonator with accelerating gradients as high as 5 MV/m and no measurable rf losses due to the tuner. Three Bellville washer stacks provide most of the restoring force and permit a tuning range of 80 kHz for an applied helium gas pressure of 1 atmosphere.

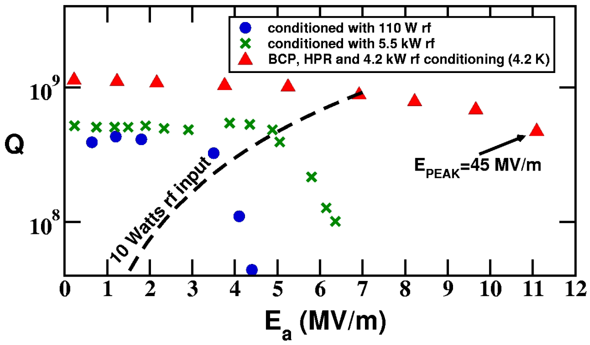


Figure 8: Top – Spoke cavity performance following BCP, high-pressure rinsing and rf conditioning compared to earlier results with only rf conditioning (bottom). The peak surface electric field, E_{PEAK} = 45 MV/m.

Figure 9: A niobium bellows slow tuner for quarter-wave resonators.

3.4 Facility Upgrades

Resonator processing facilities at ANL physics division have been installed or upgraded primarily for handling prototype drift-tube cavities being built for the RIA driver linac.

A new computer controlled high-pressure rinsing system consisting of a high-pressure pump, custom spray wands, nozzles and pneumatic motors has been installed at Argonne. The system removes particulates from the interior resonator surfaces as the final step in cavity surface preparation [12]. Figure 10 shows testing with a model cavity fastened together with the spray apparatus inside a class-100 clean area. Ultra-pure deionized water is used for rinsing purposes.

A new facility for chemical polishing has been installed at ANL permitting surface processing on resonators with closed geometries. The system operates using separate gravity fill tanks for acid and water, a water cooling tank (not shown) to remove heat from the resonator during the chemical etch and a recirculating pump to agitate the acid solution. The surface preparation laboratory at ANL maintains its longstanding electropolish capability.

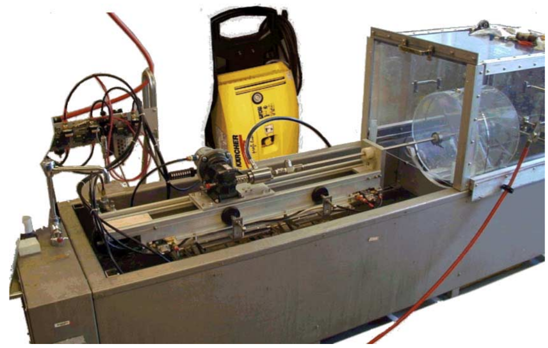


Figure 10: A new automated high-pressure rinsing system for the surface preparation of superconducting cavities.

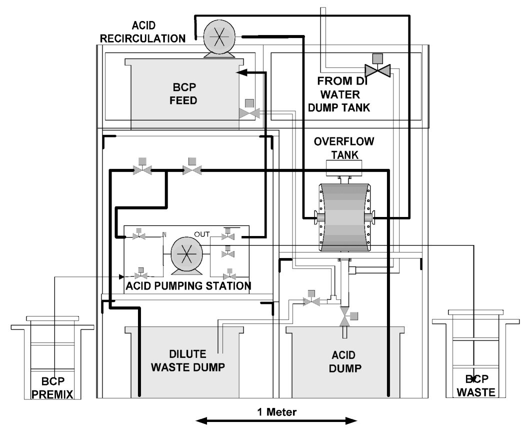


Figure 11: A new facility for buffered chemical polish (BCP) of superconducting rf cavities.

4 ADVANCED PHOTON SOURCE

Recent interest in SRF at the Advance Photon Source at Argonne has developed and is related to the application of SRF technology to a fourth generation light source. A program to measure the chemistry of niobium samples following surface treatment is already underway with the goal of providing practical information for building superconducting rf cavities [13].

Measurements based on X-ray photoelectron spectrometry (XPS) on niobium samples following heat treatment indicate a breakdown of the naturally occurring oxide layer and a substantial reduction in the secondary electron reflection coefficient (see *e.g.* Figure 12) with possible benefits related to electron multipacting.

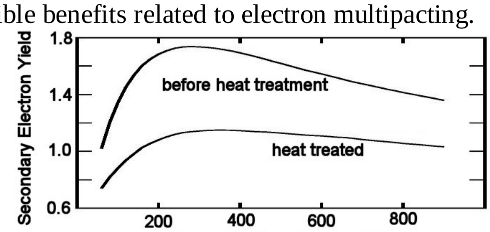


Figure 12: Secondary electron yields from a niobium sample before and after annealing at 250 ^{o}C for 19 hours.

5 ACKNOWLEDGEMENTS

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