# ACCELERATOR DEVELOPMENT FOR A RADIOACTIVE BEAM FACILITY BASED ON ATLAS

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*Abstract*

The existing superconducting linac ATLAS is in many respects an ideal secondary beam accelerator for an ISOL (Isotope separator on-line) type radioactive beam facility. Such a facility would require the addition of two major accelerator elements: a low charge state injector for the existing heavy ion linac, and a primary beam accelerator providing 220 MV of acceleration for protons and light ions. Development work for both of these elements, including the option of superconducting cavities for the primary beam accelerator is discussed.

## Introduction

Accelerator development work in the Argonne Physics Division is currently aimed at expanding the existing ATLAS superconducting heavy-ion accelerator to an ISOL-type radioactive ion beam facility (isotope separator on-line). Various concepts for such a facility have been developed and discussed within the nuclear physics community for more than a decade [1,2]. The Argonne Physics Division put forward one such concept several years ago [3]. The plan includes two linacs, a proton/light-ion linac driving a spallation source, and a radioactive ion beam (RIB) linac formed by upgrading the existing ATLAS accelerator.

The upgrade consists primarily of adding a very-low-charge-state injector, which is required to enable the efficient utilization of ion beams from a spallation source. The primary technical challenge is to provide simultaneously high beam quality and large transverse acceptance for beams as heavy as $^{132}Sn^{1+}$, or even $^{238}U^{1+}$. It has been shown that such an injector could be formed almost entirely of the same type of superconducting interdigital cavities presently employed for the ATLAS positive-ion injector[4]. With this approach, the only new technology required for the RIB linac is a cw RFQ, operating at 12 MHz, used for the first 3 MV of acceleration. Development work on the normally conducting RFQ, which is well-advanced, is described elsewhere [5].

As initially proposed, the driver linac would be a fixed velocity profile, 220 MV, normally-conducting linac. The machine would provide a total beam power of 100 kW at an energy of 100 MeV per nucleon for protons, deuterons, and ions as heavy as $^{18}O$. The different beams would be used for a variety of production mechanisms [2,3]. To be cost-effective, a normal-conducting linac would have several limitations. Firstly, to maximize shunt impedance, the velocity profile would be fixed. Consequently, the linac would have to be turned down to 100 MV for protons. Secondly, operation would be pulsed at 120 Hz, with a duty factor of at most a few percent. Such operation would aggravate heating problems in the spallation source and might also make voltage stability of the radioactive ion source problematic.

Many of these limitations could be overcome by making the driver superconducting. Since shunt impedance would not be a strong consideration, the linac could be formed of short, independently-phased cavities. The resulting variable velocity profile would roughly double the maximum proton energy. Also, cw operation would be straightforward, avoiding the problems associated with pulsed operation. At present, however, little development work has been done on

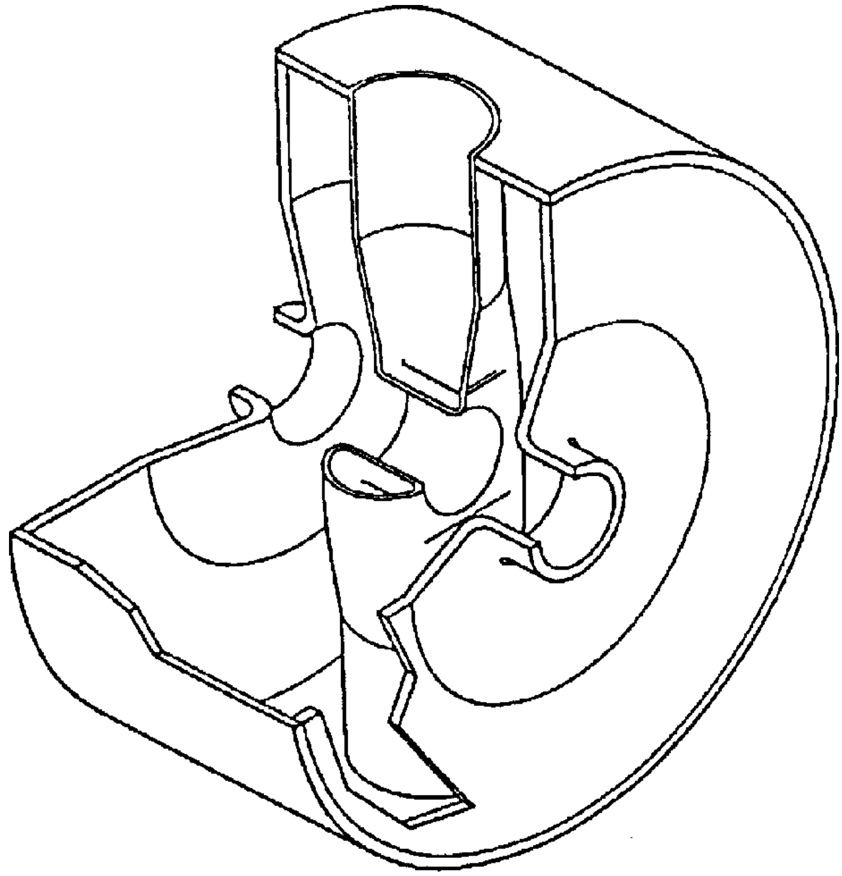

Figure 1 – A single-cell spoke cavity. The accelerating eigenmode consists of the spoke being excited as a half-wave line.

superconducting cavities with the characteristics required for such a machine. Before such a machine can be designed in detail, suitable cavities need to be fully developed.

## Conceptual Design for a Superconducting Driver Linac

A variety of superconducting ion accelerating structures have been developed for velocities $v/c < 0.2$, many of which would be suitable for the front end, or initial 18% of the driver linac. In what follows, we consider only that portion of a driver linac for $v/c > 0.2$; i.e. the new technology required for 82% of the total driver linac voltage.

Few superconducting cavities have been attempted in the velocity range required [6]. One possibility would be the medium-beta cavities currently being developed for protons of 200 MV and higher energies, which are foreshortened versions of the multi-cell elliptical cavities long used for electron acceleration. The present application, however, is aimed at energies below 200 MV, and the cavities required would be extremely foreshortened. To obtain a reasonable length and accelerating voltage, the cavity diameter will be large, on the order of a meter, and mechanical stability will be marginal. Another possible cavity geometry is the so-called spoke resonator, which

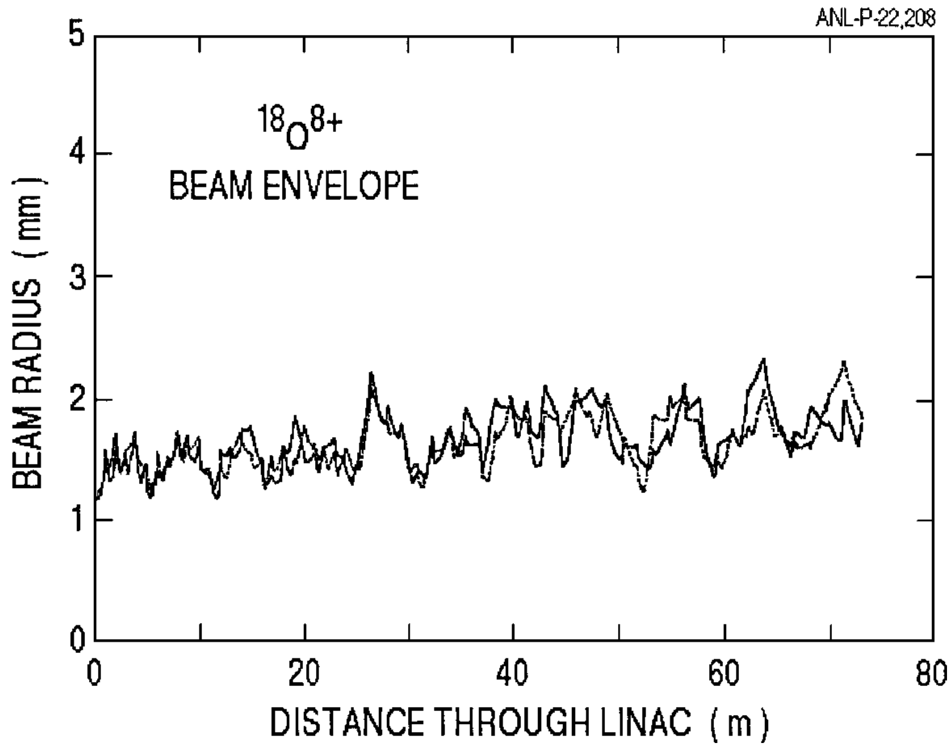


Figure 2 – Beam envelope for a $^{18}O^{8+}$ beam through a 101 cavity array forming a driver linac for a RIB spallation source. For details, see the text.

is shown in Figure 1 [6,7]. An 855 MHz, single-cell spoke cavity has been prototyped [6]. For the linac contemplated here, a lower frequency would provide more voltage per cavity: we have evaluated several possible configurations, and discuss parameter choices in detail below.

Numerical simulations have been performed for a number of possible linac configurations. Table I compares two configurations, the first consisting of two types of single-cell spoke cavity, and the second, two types of double-cell spoke cavity. The output energy for three different beams is shown. Note that for a normally-conducting, fixed velocity profile machine, the output energy of all three beams would be the lowest beam energy or 100 MeV/nucleon. In going from a one-cell to a two-cell cavity option, the output energy is reduced roughly 6% for protons because of the smaller

Table I – Comparison of two linacs: one formed of one-cell and one of two-cell spoke cavities. A frequency of 300 MHz, operation at a gradient of 5 MV/m, and an entrance velocity $\beta = 0.2$ are assumed.

| *Cavity Parameters* | *One Cell* | *Two Cell* |
|---|---|---|
| Intermediate Cavity: Length (m) | .22 | .3 |
| Optimum $\beta = v/c$ | .351 | .284 |
| Number of Cavities | 76 | 46 |
| Final Cavity: Length | .31 | .48 |
| Optimum $\beta = v/c$ | .50 | .44 |
| Number of Cavities | 84 | 56 |
| Output Energy: $^{1}H^{1+}$ | 223.3 MeV/nucleon | 208.8 |
| $^{2}D^{1+}$ | 113.7 | 113.5 |
| $^{18}O^{8+}$ | 100.3 | 100.5 |

velocity acceptance of the longer cavities. The reduction seems a modest cost, however, for reducing the total number of cavities required from 160 to 102 .

The two-cell cavity option shown in Table I has been further evaluated by numerical ray-tracing of several beams through the 102 cavity array. The lattice consisted of placing a magnetic solenoid transverse focussing element after every two (two-cell) spoke cavities. An appropriate and economic superconducting solenoid would be the 1 inch bore, 8 inch long, 8T solenoids currently employed on the ATLAS heavy-ion accelerator. Figure 2 shows the beam envelope through such a linac for an $^{18}O^{8+}$ beam. The entrance conditions were assumed to be a transverse emittance of 0.3 $\pi$ mm-mrad and a longitudinal emittance of 130 $\pi$ keV-nsec. At the output, the transverse emittance was essentially unchanged, and the longitudinal emittance had increased to 168 $\pi$ keV-nsec.

For the beam currents contemplated, 1 mA or less, space-charge effects are negligible. The large aperture typical of superconducting cavities should minimize problems of beam impingement and activation. The cost of the focussing elements will be more than a factor of ten less than for the cavities, so that even if beam impingement were an issue, it should be possible to use a solenoid bore smaller than the cavity bore to 'scrape off' any wayward beam.

## Cavity Development

The linac frequency is determined primarily by the trade-off between cavity size and voltage per cavity. An additional factor is the superconducting surface resistance, which scales with the inverse square of the frequency. Until appropriate cavities are prototyped and experimentally characterized, it is difficult to be entirely quantitative in choice of frequency, but the region 300 to 400 MHz seems most appropriate for this application, more than a factor of two lower than the only spoke resonator tested [6].

A numerically evaluated design has been put forward for a 350 MHz spoke cavity [7], the parameters of which are similar to the high velocity (300 MHz) cavities discussed above. Scaling these parameters to the $\beta = 0.48$, 2-cell spoke cavity discussed above, we would expect approximately 18 watts of rf loss due to the BCS surface resistance at 4.2 K. The BCS loss, however, represents only a lower bound. A more reasonable expectation would be the achievement of an average residual surface resistance (in addition to the BCS losses) of 10 n$\Omega$ [8]. Under this assumption, our 2-cell, $\beta = 0.48$ structure would exhibit rf losses of 24 watts/cavity at 4.2 K. This loss into the refrigeration system seems excessive, and operation at reduced temperature would be more economical for cavities of this quality: at 2.5 K, under the above assumptions, the rf loss is projected to be 7 watts/cavity. RF losses would be appreciably less in the lower velocity cavities.

## Conclusions

Projected characteristics for 300 MHz niobium spoke cavities indicate that a superconducting linac could be a high performance and cost-effective option for a driver linac for a radioactive beam facility. To establish cavity parameters on a firm basis, prototype cavities must be built and tested. To this end, construction of a prototype niobium 350 MHz, single cell spoke cavity optimized for velocity $\beta = 0.44$ has been initiated, with initial tests expected in late calendar 1998. If funding permits, a two-cell version of this structure, as well as $\beta = 0.28$ structures, will also be initiated.

## Acknowledgements

The authors gratefully acknowledge several helpful conversations with Jean Delayen and the help of Patricia Vahle in performing electromagnetic field measurements on a series of model spoke cavities.

## References


1. Proceeding of the Accelerated Radioactive Beams Workshop, September 5-7,1985, Parksville, Canada, edited by L. Buchmann and J. M. D'Auria, TRIUMF report TRI-85-1.
2. J. A. Nolen, in Proc. of the 18th International Linac Conference, August 26-30, 1996, Geneva Switzerland, p32 (1997).
3. "Concept for an Advanced Exotic Beam Facility", a working paper, Physics Division, Argonne National Laboratory, February, 1995.
4. K. W. Shepard and J. W. Kim, 1995 Particle Accelerator Conference and International Conference on High-Energy Accelerators, Dallas, Texas, May 1-5, 1995, p1225 (1995).
5. K. W. Shepard and W. C. Sellyey, in the Proceedings of the 1996 Linear Accelerator Conference, 26-30 August, Geneva Switzerland.
6. J. R. Delayen, W. L. Kennedy, and C. T. Roche, Proc. of the 1992 Linear Accelerator Conference, August 24-28, 1992, Ottawa, Canada, AECL-10728, p695 (1992).
7. J. R. Delayen, et al., Proc. of the 1993 Particle Accelerator Conference, May 17-20,1993, Washington D.C.,IEEE 93CH3279-7, p1715 (1993).
8. F. Palmer, Proc. of the 3rd Workshop on RF Superconductivity, September 14-18, 1987, Argonne, Illinois, p309 (1988).