RPI LINAC refurbishment and upgrade project

Yaron Danon,* Peter Brand,* Michael Bretti,* Brian Epping,† and Timothy Trumbull†

*Gaerttner LINAC center, Rensselaer Polytechnic Institute , Troy, NY 12180, danonyj@rpi.edu
†Naval Nuclear Laboratory, P.O. Box 1072, Schenectady, New York 12301-1072
doi.org/10.13182/T125-36734

INTRODUCTION

The Electron Linear Accelerator at Rensselaer Polytechnic Institute (RPI) was constructed in the late 1950s and started operation in 1961 [1]. The facility was designed and used primarily for measurements of Nuclear Data (ND) with emphasis on the resonance energy region. As such it was designed to produce short pulses of neutrons (5-5000 ns) and equipped with detection stations at different neutron flight path distances from the source (15 m-250 m). When the LINAC started operation it was one of the most powerful accelerators in the world for high energy-resolution measurements in the resonance region. The original LINAC with some upgrades is still in operation but no longer provides world class capabilities for measurements with short pulses. In 2011 discussions between the RPI ND group, Naval Reactors, and the Nuclear Criticality Safety Program about the future of the LINAC concluded that maintaining the capability to perform world-class nuclear data measurements at RPI was desirable. To that end, it was decided to refurbish the facility and upgrade the accelerator capabilities to enable high accuracy measurement in the resonance region with narrow neutron pulse and high electron beam power.

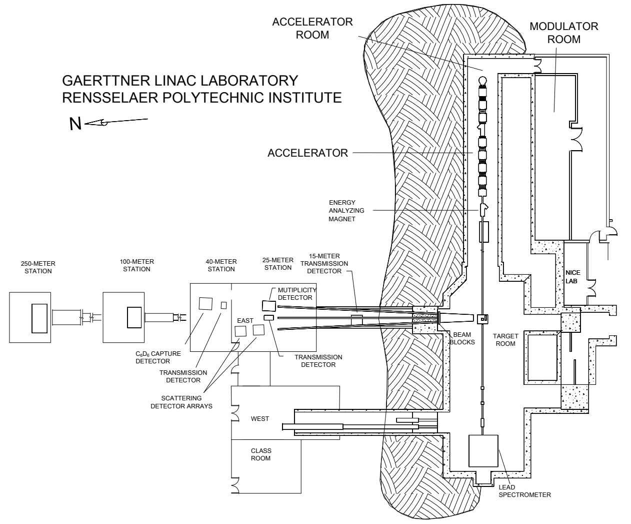

Fig. 1. Layout of the RPI LINAC facility showing the accelerator, target room, and the neutron beam lines that are at angle of about 90 deg relative to the electron beam line.

Located at a major US technical university, this project provides a needed US nuclear data capability for both research and education, and also includes external users and industrial applications.

CURRENT ACCELERATOR

The original accelerator operated at pulse repetition rate of 1-500 Hz and originally accelerated electrons to an energy of up to 100 MeV. The maximum average electron beam power of the LINAC was about 22 kW when operating with a pulse width of ≈4 μs. The electrons are converted to neutrons using a water cooled tantalum target (see for example [2]). The original accelerator was a nine sections machine which included nine modulator-klystron pairs, producing high-energy radio-frequency (RF) waves to drive each of the accelerating sections, a layout of the facility is shown in Figure 1 where the accelerator, neutron beam lines, and detector stations are shown. Over the years two major upgrades were necessary. In 2000 a new set of klystrons was purchased and installed, and in 2005 the electron injector was upgraded to allow better operation at short pulse.

The capabilities of the current accelerator that are relevant to ND measurements are given in Table I. The original LINAC was designed to address the nuclear data needs of the early sixties and they were mostly related to thermal reactors. The low energy resonance and thermal energy regions (E<1 eV) are most important for thermal reactors, and many cross section measurements were done in these energy ranges. Measurements in the low energy range do not demand very long flight paths or very narrow neutron pulse width and the RPI accelerator excelled in this low energy range. At that time there was also a great need for better understanding of the slowing down process and thermal scattering kernels that were measured at RPI included water at different temperatures, ZrH, and UO_2 [3].

Over the years the Nuclear Data needs shifted to also include higher energies, including both the keV and MeV energy ranges. In the 0.5-20 MeV range the neutron flux of the current LINAC enables cross section and neutron scattering measurement with reasonable run times, but for keV experiments such as neutron capture and transmission which requires a short pulse, the neutron flux is low and this requires longer run times. An improvement in the short pulse neutron flux will also help overcome time independent background (room background) especially in capture measurements.

UPGRADED ACCELERATOR - NEW CAPABILITIES

The upgraded accelerator design goals are to improve the neutron production and provide longevity of operation while fitting within the current target room shielding and size. With this in mind operational modes required for the expected future ND measurements were developed. An improvement was needed in short pulse operation

TABLE I. Typical Nuclear Data relevant modes of operation of the current accelerator.

Mode	Beam Energy [MeV]	Pulse Width [ns]	Repetition Rate [Hz]	Average Power [kW]
Short pulse	52	6-10	250-400	0.3-0.5
Long pulse	52	200-1,000	18-25	0.4-1
High Power	52	3,000-4,000	100-250	1-12

TABLE II. Modes of operation of the upgraded accelerator.

Mode	Beam Energy [MeV]	Pulse Width [ns]	Repetition Rate [Hz]	Average Power [kW]
Short Pulse	150	5	≤800	≥7
Low Rep. Rate	60-150	≤250	25	≥1
High Average Power	45-150	Any	≤800	≥45
Low Energy	0-10	0 to ≥ 25	Single to Maximum	Any

required for high energy-resolution measurements in the keV region with enriched isotopes of stable and possibly unstable elements. It was also important to keep additional capabilities for thermal measurements and high power operation that are useful for development of future research. The new specifications are give in Table II. These new modes of operation emphasize the needed short pulse and high power.

In addition to design requirement in Table II, it was required to lower the cost by using off-the-shelf major components such as klystrons and modulators that were predefined and selected. It was decided to continue to use an L-band machine that works on stored energy with a conventional copper-based section design. Once the high level specifications were outlined, the design of the accelerator was subcontracted to SLAC National Accelerator Laboratory and is documented in references [4] and [5].

Accelerator layout

The new accelerator design is an L-band electron LINAC with nine acceleration sections and five klystrons and modulators. The system includes one tapered phase velocity (TPV) section to bunch and accelerate a train of bunches, and eight speed of light (SOL) sections. One klystron is feeding radio frequency (RF) to the TPV and each of the other klystrons feeds two SOL sections accelerating the electrons up to 150 MeV. A simplified layout of the LINAC is shown in Figure 2. The new accelerator is slightly longer than the current but fits in the existing room. It was calculated that no major change to the existing shielding is required.

Upgrade status

The design of the accelerator was completed and documented in [5], complete design drawings were delivered to RPI and work on acquiring components and building the new LINAC started. The major components: klystrons from Thales, RF modulators from ScandiNova Systems, AB, and

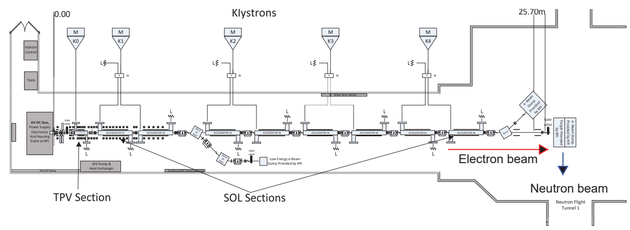

Fig. 2. Layout of the new LINAC showing nine acceleration sections driven by five klystrons.

accelerating sections from Radiabeam were ordered and some delivered to RPI. The current schedule is to permanently shut down the existing LINAC in mid-2022 and have the new LINAC operational in 2024.

The construction of the accelerator requires changes to the site infrastructure that were planned for two phases, phase I was completed in 2019 and includes a new building that will become the new modulator room with additional ceiling height to be able to service the klystrons. In phase II the current LINAC will be dismantled and additional water and electrical infrastructure will be installed prior to installation of the new accelerator.

At present a setup for full power testing of a modulator and klystron was built as shown in Figure 3 and will be extended to also test a SOL accelerator section prior to fabrication of additional sections.

CONCLUSIONS

The Nuclear Data program at RPI is utilizing a 60 MeV electron LINAC at Gaerttner LINAC Center for measurements that are relevant to applications including nuclear reactors, criticality safety, medical isotopes, and radiation damage to electronics. An upgraded LINAC will replace the current accelerator and will accelerate electrons to energy of 150 MeV while delivering 7 kW of average power at a 5 ns wide elec-

Fig. 3. A test station used for testing a modulator, Klystron and RF windows.

tron pulse. For these conditions it will provide an order of magnitude increase in neutron production which will enable measurement of small enriched samples using more sophisticated experimental setups. Operating at a wide pulse width the accelerator can deliver up to 45 kW of electron beam power with neutron production suitable to measurements in the thermal energy range and electron power suitable for medical isotope production. The new accelerator is a modern accelerator based on solid-state technology, with computer controlled operation and beam diagnostics. The Gaerttner LINAC Center will continue to provide pulsed beams for nuclear data measurements in support of the NNSA Nuclear Criticality Safety Program (NA-511), Naval Reactors Program (NA-30), and other education and research opportunities. Electron, photon, and neutron beam time will continue to be available to external users.

ACKNOWLEDGMENTS

This work was supported by DOE grant DE-NR0000679 and partially by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.

REFERENCES

1. E. GAERTTNER, M. YEATER, and R. FULLWOOD, "Rensselaer Polytechnic Institute Linac Facility," in M. YEATER, editor, "Neutron Physics," Academic Press, pp. 263–288 (1962).
2. Y. DANON, R. BLOCK, and R. SLOVACEK, "Design and Construction of a Thermal Neutron Target for the RPI LINAC," *Nucl. Instrum. Methods Phys. Res., Sect. A*, **352**, *3*, 596–604 (1995).
3. F. BISCHOFF, W. BRYANT, L. ESCH, C. LAJEUNESSE, S. P. W.E. MOORE, S. PUROHIT, and M. YEATER, "Low-Energy Neutron Inelastic Scattering," Tech. Rep. progress report, No.328-87, p.73, EXFOR entry 13921, Rensselaer Polytechnic Institute (1967).
4. C. ADOLPHSEN, K. BANE, V. DOLGASHEV, A. JENSEN, A. HAASE, E. JONGEWAARD, M. KEMP, A. KRASNYKH, J. LEWANDOWSKI, Z. LI, J. NEILSON, C. PEARSON, S. TANTAWI, J. WANG, A. D. YEREMIAN, P. BRAND, Y. DANON, B. EPPING, T. DONOVAN, R. BLOCK, and G. LEINWEBER, "Conceptual Design for the New RPI 2020 Linac," (2014).
5. V. DOLGASHEV, M. FRANZI, A. JENSEN, A. HAASE, E. JONGEWAARD, M. KEMP, A. K. Z. LI, J. NEILSON, A. SY, J. WANG, G. WHITE, A. YEREMIAN, P. BRAND, Y. DANON, B. EPPING, and T. TRUMBULL, "DESIGN OF THE NEW RPI 2020 LINAC," Tech. Rep. SLAC Report: SLAC-R-1126, SLAC (2019).