Crocker Nuclear Lab Vision Statement

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I believe the Crocker Nuclear Lab (CNL) cyclotron has great potential for both research and education, and I feel that I am well qualified to help it reach that potential. I should start by saying a few words about my background as it relates to this project.

From 2004 to 2008, I was head of the Proton Source at Fermilab, which includes the 8 GeV proton booster. This is a department with 35 people and an annual budget of approximately $3M. Like the Crocker cyclotron, this was an old machine which was being asked to perform well beyond its design. When I arrived, it was just delivering protons for antiproton production, and was already becoming radioactive. The MiniBooNE experiment and the MINOS experiment would require it to increase its output by a factor of 20, while a limit of no more than a factor of two was imposed on the activation. Achieving this required a campaign of both physical improvements to the machine and an effort to understand the physics of its operation to understand and mitigate beam loss. This campaign became the first "Proton Plan" project [1]. There were many components to this plan, but it culminated in a new corrector system, for which I wrote the specifications, which is only now realizing its full potential [2].

In 2008, I was selected as director of the US LHC Accelerator Research Program (LARP) [3]. This program coordinates US activities related to the LHC accelerator itself, complementing the significant US involvement in the LHC experiments. The program funds R&D at Fermilab, Brookhaven, LBL, SLAC, and occasionally at universities. As director, I managed a $12-13M/year budget, about half of which went to developing new, high gradient quadrupoles based on Nb3Sn superconductor, and the rest of which funded numerous accelerator physics and instrumentation efforts. LARP also supported personnel programs, including the Toohig Postdoctoral Fellowship. During my tenure, the LARP program was integrated with the HiLumi-LHC program in Europe, and it culminated in a set of US deliverables for the high luminosity upgrades to the LHC, currently scheduled for the early 2020s [4]. For my work on LARP, I was given a recognition award from the DOE and elected as a Fellow of the APS.

For the last two years or so, I've been in charge of implementing proton injection into the Integrable Optics Test Accelerator (IOTA) at Fermilab. IOTA is designed to test new concepts in particle beam storage. By using optics involving nonlinear magnetic fields, it is hoped to create orbits which are stable and analytical, but which have no unique tunes, thereby making them insensitive to harmonic instabilities and thereby allowing much more intense beams than those possible with conventional synchrotrons. The optics will initially be tested with electrons, but my work involves refurbishing a 2.5 MeV proton RFQ which was originally designed for the Fermilab High Intensity Neutrino Source (HINS) and adapting it for use in IOTA [5]. This includes designing – together with a graduate student - and constructing the required beam transport, was well as developing instrumentation for the IOTA ring. This project involves hardware design and oversight as well as beam calculations and simulation.

I feel these experiences make me qualified to direct the CNL, both in terms of management experience and technical ability. In broad strokes, my goals for the facility would be to continue the ongoing work in ocular cancer treatment and radiation damage studies, while expanding the program into other areas, as outlined below.

Radiation Damage Studies

CNL has been used continuously for radiation damage studies, but these have traditionally focused on testing the effects of radiation on specific electronics or other hardware. I would propose that the effort expand into a more fundamental exploration of the physics of radiation damage. I have discussed this with Nikolai Mokhov, the head of the Fermilab Energy Deposition Group, and he is very excited about the opportunity to do fundamental energy deposition studies with the Crocker Cyclotron, particularly with a new heavy ion source installed. Such studies would also include secondary neutron beams, and could be augmented by measurements at the McLellan Nuclear Research Center reactor.

Nuclear Cross Section Measurements

Given the importance of stockpile stewardship and the interest in Accelerator Driven Subcritical (ADS) systems, there is renewed interest in a suite of fundamental low energy nuclear structure and cross-section measurements. In this role, the CNL cyclotron could be very complementary to the 88-inch LBL cyclotron and other facilities. This would involve resurrecting and modernizing the nuclear physics instrumentation equipment at the lab.

Isotope Production

Table 1: Isotope production capabilities of the CMGI cyclotron, MNRC reactor and CNL cyclotron.

Facility	Description	Isotope Capability
UC Davis CMGI	Siemens 11 MeV cyclotron – H^+	^{11}C,^{13}N,^{15}O,^{18}F, ^{64}Cu,^{89}Zr,^{124}I
UC Davis MNRC	2 MW TRIGA reactor	^{24}Na, ^{35}S, ^{41}Ar,^{55}Co,^{64}Cu, ^{72}Se,^{82}Br,^{105}Rh,^{128}Cs, ^{131}Cs,^{130}La,^{147}Pm,^{153}Sm
UC Davis CNL	76 in isochronous cyclotron H+ 4-68 MeV, D+ 4-40 MeV He2+ 8-80 MeV	^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{72}Se, ^{86}Y,^{89}Zr,^{128}Cs,^{211}At

The CNL cyclotron once produced short lived radioactive isotopes for medical purposes, and I would propose to bring that capability back, and perhaps coordinate it with the McLellan reactor. The university has in house capability to produce isotopes in support of the medical program, and to that end has an 11 MeV Siemens H+ cyclotron dedicated to isotope production; however, as Table 1 shows, both the MNRC reactor and the CNL cyclotron have complementary capability.

Biophysics

The potential in this area is particularly exciting, because it is an opportunity to combine the detector capabilities of the physics department with the expertise in the Biology Department and medical school. Of particular interest are plant dynamics, including transport dynamics and root soil interfaces. Study techniques would be a combination of tomography of radioactive tracers and precision neutron radiography.

Medical Physics

Hadron therapy has become increasingly popular in recent years; however, most facilities are fully subscribed commercial installations, and available research time is limited. As a proton therapy facility, the energy of the CNL is a bit low for general use, but there are certainly niche applications. It has already been used to treat ocular melanoma, and perhaps other forms of cancer that are not too deep. In addition, we can investigate deuteron and alpha therapy, and there is even the possibility of adding a Carbon source.

If the current of the cyclotron can be increased to its design value of multiple mA, it also opens the possibility of creating a neutron therapy line. Neutron therapy was pioneered at Fermilab, and was used to treat patients for many years. With the shutdown of the facility a few years ago, there are currently no neutron therapy facilities in the US, although it is still indicated over charged hadron therapy for a variety of cancers.

Accelerator Physics

Although cyclotrons have been around a very long time, there are still interesting problems involved in producing intense and high quality beams. The CNL cyclotron could serve as a study tool and test bed for the physics of beam formation. The large pole gap leaves open the possibility for novel instrumentation to study these things.

Some of this instrumentation would likely by synergistic with work being done for the IOTA project which I discussed earlier, and could possibly be the basis for a graduate thesis research sponsored by the Joint Fermilab-University PhD program, which I describe in my teaching statement.

Required Upgrades

The CNL cyclotron will need numerous upgrades to reach its full potential, the exact scope of which have yet to be determined. Luckily, they can be done adiabatically, hopefully without introducing excessive down time.

First and foremost, the control system of the cyclotron is antiquated and its operation is extremely labor intensive. Luckily, this can be remedied with fairly modest upgrades. A cyclotron is not a particularly complex device, and all operational parameters could be put under the control of a simple processor or PLC, enabling much more turnkey operation. Such a project, or aspects of it, might even be appropriate for an engineering Master’s student.

The next question involves increasing the current of the cyclotron. It was designed as a multi-mA machine, but is typically operated only at very small currents, which limits its potential applications. Part of this limitation comes from shielding, which could be easily upgraded, but there also appear to be hardware limitations that are not fully understood.

Other potential upgrades, such as the high power RF system or magnet power supplies, would have to be considered on a cost benefit basis.

Education

The CNL cyclotron affords many educational opportunities, which are outlined separately in my "Teaching Statement" document.

References

[1] E. Prebys, B. Baller, and J. Spalding, "The Proton Plan", FNAL-BEAMS-DOC-1441, http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=1441

[2] E. Prebys, J. Lackey, and D. Harding, "Booster Corrector System Specification", FNAL-BEAMS-DOC-1430, http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=1430

[3] http://uslarp.org/

[4] E. Prebys *et al*, "Proposed US Contributions to LHC High Luminosity Upgrade", LARP-DOC-1070, http://larpdocs.fnal.gov//LARP-public/DocDB/ShowDocument?docid=1070

[5] E. Prebys *et al*, "Proton Injection into the Fermilab Integrable Optics Test Accelerator (IOTA)", WEPWA055, Proceedings of the 6th International Particle Accelerator Conference (2015), http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/wepwa055.pdf