PROPOSED UPGRADE OF THE NSCL*

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Abstract

The present nuclear physics program at the National Superconducting Cyclotron Laboratory (NSCL) is based on an ECR-ion-source-injected K1200 superconducting cyclotron. We propose to significantly increase the facility's output intensity for light ions and energy for heavy ions by coupling the existing superconducting K500 cyclotron's output to the K1200. The improved acceleration chain will consist of an ECR-ion-source-injected K500 cyclotron to accelerate ions to ≤ 17 MeV/nucleon followed by radial, charge-stripping injection into the K1200 for final acceleration to 100-200 MeV/nucleon.

	^{11}Li	^{19}Ne	^{32}Mg	^{56}Ni	^{132}Sn
K1200 & A1200	2.5×10^3	6×10^7	1.2×10^3	7×10^4	2
K500⊗K1200 & A1900	4×10^6	1×10^{10}	3×10^6	1×10^8	4×10^4

Table I
Intensities (ions/sec) of representative radioactive beams achievable with K1200 stand-alone operation compared to those predicted for the K500⊗K1200 coupled cyclotron operation using the A1900 fragment separator.

I. INTRODUCTION

The NSCL proposes to couple its two superconducting cyclotrons (K500 and K1200) and to replace the existing fragment separator (A1200) with one of increased capacity (A1900) as shown in Figure 1. Since the upgrade relies on the existing cyclotrons and incorporates the present experimental facilities, it can proceed in a timely (~4 - 5 years estimated project duration) and cost-effective fashion (~ 19M FY94 US\$ in total project costs including labor and materials).

The coupling of the cyclotrons (K500⊗K1200) will provide significant increases in the primary beam intensity and for the heaviest ions, in beam energy permitting a wide variety of experimental programs to be undertaken which are presently not feasible.

II. PERFORMANCE

The maximum theoretically achievable energy is determined by the characteristics of the K1200 cyclotron. The improvements in energy and intensity that come with coupling the cyclotrons result from the lower charge states required from the ECR ion source for the K500⊗K1200 mode. These lower charge states needed from the ECR to achieve the same final energy have significantly more intensity than the higher K1200 stand-alone charge states.[1]

Large gains in intensity are possible for all ions considered, and in addition, there are significant gains in energy for mid and high-mass nuclei. Figure 2 shows these gains and also illustrates the possible trade-off of intensity for energy. Shown are contours of intensity as a function of E/A and A for the K500⊗K1200 operation (solid lines) and the present K1200 stand-alone operation (dashed lines). The intensities are also given at specific points

for the K500⊗K1200 operation (solid) and stand-alone operation (open). For heavier beams, the intensity gains for highly charged ions effectively result in higher energy beams (by factors of 2 - 4). Note that energies of over 100 MeV/nucleon are possible for uranium, while intensities up to 6×10^{12} particles/s are possible for lighter ions.

The greater intensities for the lighter ions are an excellent match to the needs of the growing field of nuclear physics research using radioactive ion beams, as they can be converted into very intense, good-quality secondary beams. To fully capitalize upon the increased primary beam intensities for the production of secondary radioactive beams, a large projectile-fragment separator (A1900) is proposed. In order to produce and separate rigid neutron-rich nuclei at optimal production energies, the A1900 will have ~30% greater bending power than that of the cyclotron (K1200), and will have a collection efficiency for fragmentation products approaching 50% compared to the 2-4% for the present NSCL system (A1200). Intensities for some representative ions are given in Table I.

III. DESIGN

Some parameter details for the injection chain are given in Table II. Ions of charge state Q_1 will be produced in an ECR ion source, transported from the ion source area to a point below the K500 and axially injected into the K500 central region. Ion intensities of ~ 10^{13} particles/s will be accelerated in the K500 in approximately 230 turns to energies of $\leq$ 17 MeV/u. The beams will then be transported to the K1200 with a system of magnetic elements and an rf system (used to control the bunch length between the two cyclotrons) and injected through an existing horizontal port to a point at approximately one third of the K1200 extraction radius (~0.33 m) where they will be stripped to a higher charge state Q_2. Finally, the beam of charge state Q_2 will be accelerated in the K1200 to final energies of $\leq$ 200 MeV/u and extracted. Following the K1200, the extracted beam will be
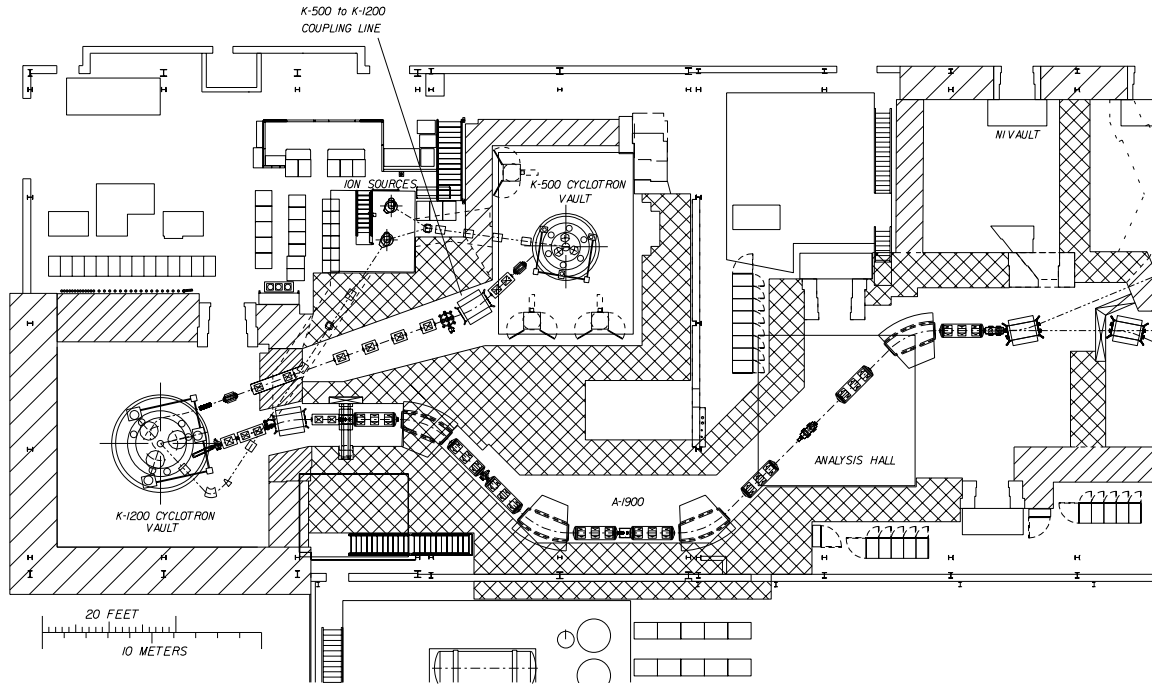
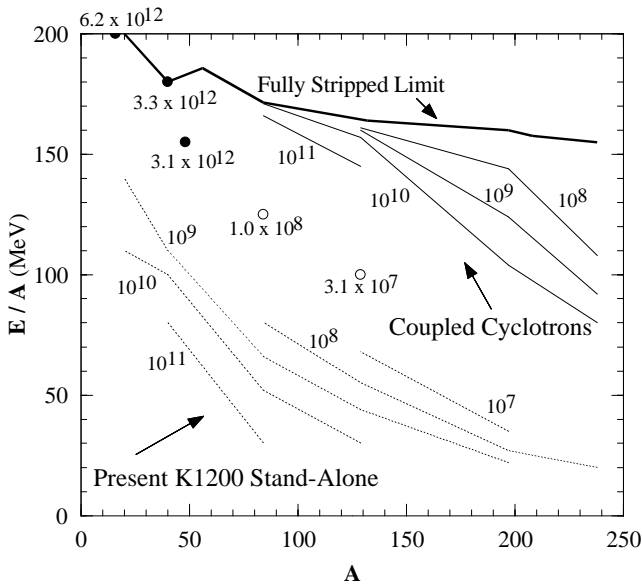Figure 1. Proposed new accelerator area of the National Superconducting Cyclotron Laboratory.

Figure 2. Operating diagram for the present K1200 stand-alone cyclotron and the K500⊗K1200 system. Intensity contours in particles per second are given for the K1200 stand-alone cyclotron (dashed) and the K500⊗K1200 (solid). The intensity is also given at speci®c points for the K1200 stand-alone (open) and the K500⊗K1200 (solid) operation. The present K1200 stand-alone performance contours are based upon the performance of the room temperature ECR with speci®c points (open) based upon the superconducting ECR performance.

Ion	K500		Strip.	K1200		
	Q_1	Energy (MeV/u)	Ef®c. %	Q_2	Energy (MeV/u)	Intensity (part./s)
^{16}O	3	16.7	100	8	200	6.2×10^{12}
^{84}Kr	15	14.7	2.2	36	170	2.1×10^{10}
^{238}U	32	8.6	2	74	90	1.2×10^{9}

Table II
K500⊗K1200 parameter details for selected ions.

optically matched to a new beam analysis system, the A1900. As with the present A1200 analysis system, the A1900 will be positioned as the ®rst element of the switch yard so that any beam, including separated fragments, can be delivered to any of the experimental areas.

IV. PROJECT SCOPE

The operating voltage of the existing superconducting and room temperature ECR ion sources will be increased from ~ 20 kV to ~ 30 kV in order to mitigate space charge effects, increase the beam brightness, and reduce the deleterious effects of the K500 fringe ®elds on the injection process. The existing coupling line between the K500 and the ECR ion sources will be modi®ed in order to provide for ef®cient transport of high intensity beams.

The K500 cyclotron will be refurbished to obtain the operating reliability which is currently achieved by the K1200 cyclotron ($>90\%$). During the refurbishing process, the K500 will be disassembled with reassembly in a position rotated 120° from its present position to orient the extraction channel towards the K1200. In addition to the implementation of proven K1200-like engineering solutions, a new central region will be used to allow

Task	Funding Required (FY94 M$)
ECR/Injection Upgrade	0.50
K500 Upgrade	3.08
Coupling Line	2.11
K1200 Upgrade	1.29
A1900	4.46
Building Systems Upgrades	3.67
Commissioning	0.15
Total	**15.26**
Contingency (∼25%)	**3.68**
Grand Total	**18.94**

Table III
K500⊗K1200 Costs in FY94 M$.

Item	Achieved	K500⊗K1200 Specification
ECR to K500 Transmision	$\geq$50%	50 %
ECR Voltage	20 kV	$\leq$30 kV
K500 Injection Ef®ciency	∼5%	6 %
K500 Extraction Ef®ciency	∼80%	90%
Overall Transmission	∼2%	2.7%
Extracted Emittance (πmm-mrad)	∼10	∼3

Table IV
Results achieved to date compared to K500 speci®cations for the K500⊗K1200 system.

more ef®cient operation at the second harmonic and a higher performance extraction septum will be installed.

A new coupling line between the K500 and the K1200 will be implemented. In the K1200, the injection hardware will be installed and the extraction hardware improved. (The capability to operate the K1200 cyclotron in the stand-alone mode will be retained.) The present fragment separator (A1200) will be replaced with a much higher performance system (A1900).

The NSCL high bay area will be extended by approximately 25 m in order to provide a staging area for magnet construction and refurbishing of the K500. A building addition will be constructed near the present cryogenic plant to house a cryogenic system of increased capacity, and the radiation shielding will be increased.

The total project costs are given in Table III.

V. PRESENT STATUS

The design concept for the K500⊗K1200 was developed during 1993-1994. A conceptual design report was published [2] and a proposal was submitted to the National Science Foundation (NSF) in 1994 in which a cost sharing strategy between Michigan State University (8 FY94 M$) and NSF (11 FY94 M$) was speci®ed. Since that time, research and development projects have begun on certain aspects of the design. MSU has already committed a portion of its contribution (∼ 1 M$) for the extension of the high bay area with construction scheduled for completion near the end of 1995.

Detailed design and initial prototyping of programmatic elements such as the coupling line rf system and the stripping foil system to be used in the K1200 are in process.

The superconducting ECR has been tested up to a platform voltage of 25 kV. However, due to limitations in the ECR to K500 transport system only beam energies compatible with a platform voltage of 20 kV can be effectively transported to the K500 at the present time.

A new second harmonic central region for the K500 [3] has been designed and fabricated, and commissioning is well underway. Existing internal beam probes have been refurbished and bunch length diagnostics have been designed and implemented. The K500 extraction system geometry has been modi®ed appropriately for K500 operation in the K500⊗K1200 mode, although the power handling capacity remains to be developed. Recent results of the ECR through K500 extraction system are given in Table IV. These initial results are quite encouraging since the K500⊗K1200 speci®cations are nearly met even though critical elements such as the improved ECR to K500 injection line remain to be implemented. Bunch lengths meeting design speci®cations (3° FWHM) and intensities at ∼ 55% of the design requirement (6×10^{12} particles/s) have been achieved, although not simultaneously. In the near term, efforts will be directed towards achieving the nearly realized goal of extracting beams from the K500 which meet the K500⊗K1200 speci®cations.

References

[1] Richard C. York, T.A. Antaya, Henry Blosser, Don Lawton, Felix Marti, D.J. Morrissey, B.M. Sherrill, John Vincent, and A.F. Zeller, ªPresent Status and Future Possibilities at NSCL-MSUº, Proc. 4th European Part. Accel. Conf., London, England,June 1994,pp. 554-556.

[2] ªThe K500 ⊗K1200 - A Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratoryº, July 1994, Michigan State University, East Lansing Michigan, MSUCL-939.

[3] S. L. Synder and F. Marti, ªStudy and Redesign of the NSCL K500 Central Regionº, these proceedings.