Cyclotron institute upgrade project

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On January 3, 2005 the Cyclotron Institute Upgrade Project (CIUP) began with the approval of the CIUP management plan by the Department of Energy Nuclear Physics Office. The project will extend to the first quarter of calendar year 2011. When completed, the upgraded facility will provide high-quality re-accelerated secondary beams in a unique energy range in the world. Funding for the upgrade comes from several sources: the Department of Energy, matching support from TAMU, the Robert A. Welch Foundation and beam time sales for testing electronics components at the Cyclotron Institute.

The CIUP is divided into three major tasks: (1) Re-commission of the existing K150 (88") cyclotron and refurbish beam lines; (2) Construct light-ion and heavy-ion guides and produce 1+ radioactive ions; (3) Transport and charge boost radioactive ions and accelerate these in the K500 cyclotron.

Most of the effort during this reporting period focused on Task 1, restoring the K150 cyclotron major equipment. This included commissioning the K150 cyclotron initial vacuum system, coil power supplies and sub-systems. Each component of the K150 RF system has been tested and full commissioning should take place in early summer 2007. Installation of K150 ECR & injection line and assembly of K150 beam line equipment has begun. The ECR & injection line should be completed by mid summer 2007, and the beam line should be functional by spring 2008. Progress was also made on Tasks 2 and 3. This included testing of the light ion guide chambers vacuum equipment and development of the SPIG ion transport device. The beam dump and radiation shielding has been designed by utilizing complex radiation transmission computer codes. The design was approved by a panel of experts that visited in March 2007. Development of heavy ion guide gas cell system with collaboration with ANL and GSI still continues. The CBECR ion source constructed through a DOE SBIR project is nearly complete. The CBECR is scheduled to arrive in September 2007. Below is a description of the progress made. Figure 1 illustrates the revised project schedule and major milestones.

TASK 1:

1) **K150 Cyclotron Vacuum System:** The design calls for vacuum equipment to be installed on the two main sections of the vacuum space (resonator tank and dee tank) as follows: The resonator tank will be equipped with one new 35" diffusion pump with a modern cryogenic baffle system and one new roots blower package (initial system). The initial system will provide a vacuum pressure of 5×10^{-6} torr for testing the RF System, identifying any major leaks and producing first beams. The dee tank will be equipped with one internal liquid nitrogen cryogenic panel and four external cryopumps (high vacuum system). The high vacuum system will provide a vacuum pressure of low 10^{-7} torr for beams later in the project.

   All components of the initial system (35" diffusion pump, cryobaffle and roots blower) have been procured and installed on the cyclotron including electrical power, interlock/control system, cooling water and pneumatic control. For the high vacuum system, the external cryopump system (four pumps, two compressors and helium transfer lines) and VAT isolation valves have been procured.

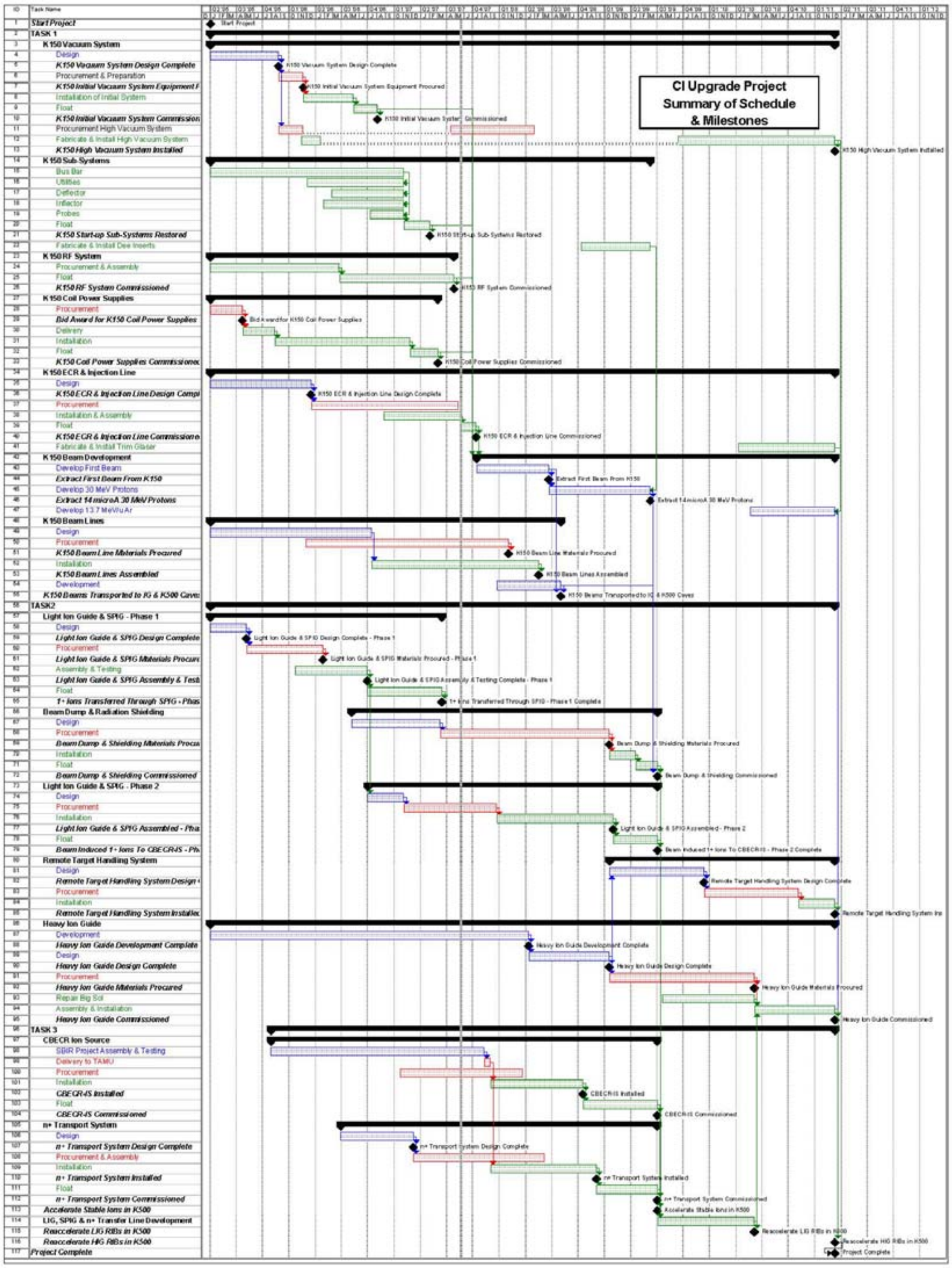

Figure 1. The project schedule and major milestones.

The VAT valves for the external cryogenic system have also been installed. A quote for the LN2 transfer and dewar system has been received from Technifab Inc. This system will be used to feed LN2 to both the internal cryopanels of he cyclotron and to the cryopanel system in the vertical injection line. Materials for the cryogenic panels are being procured.

In late September 2006, the initial system was turned on, and all large external vacuum leaks were identified and repaired. After ~20 hours of pumping, vacuum was measured to be $2x10^{-6}$ torr at the bottom of the resonator tank (closest to the diffusion pump) and $2x10^{-5}$ torr at the top of the resonator tank (furthest from the diffusion pump). Initial start-up showed that the initial system was functioning properly and according to design.

In March 2007, several leaks were identified at various locations outside and inside the cyclotron and were repaired. After repairs were made, noticeable improvement was observed. Vacuum of 2x10-6 torr was measured at the extraction region of dee tank and also at the top of the resonator tank (locations furthest from the 35" diffusion pump). Vacuum was also measured to be 2x10-7 torr at the bottom of the resonator tank, which is closest to the 35" diffusion pump. Pump down time from atmosphere to these values was recorded to be several hours which was also a significant improvement.

2) **K150 Cyclotron Buss Bar Work:** Buss bar installation is complete for all twenty three coil power supplies, including the final connections to the main coil power supply. The main coil power supply arrived in late June 2006 and has been installed.

3) **Upgrade Project Utilities:** The building power improvement (to add electrical power capacity for the K150 cyclotron, K150 coil power supplies, K150 RF system, K150 beam lines, ion guides, etc.) is complete. All Upgrade Project equipment is now utilizing the new building power improvement including the K150 vacuum system, K150 RF system and the Light Ion Guide vacuum system.

   Construction of the new LCW loop (to add cooling water capacity for the K150 cyclotron, K150 coil power supplies, K150 RF system, K150 beam lines, ion guides, etc.) is complete. All pipes, connectors, valves, pumps and control gear have been installed including the surge tank, demineralizer, heat exchanger and cooling tower pumps. The start-up occurred during annual maintenance (January 2007). This new LCW system will provide water to the K500 experimental beam lines. Since the inception of the K500 cyclotron, the 88" LCW system provided this water, however now the 88" LCW system has been restored to the K150 cyclotron.

4) **K150 Cyclotron Deflector:** Two new Spellman deflector power supplies were purchased. Installation of the supplies and control equipment is complete. The deflector assembly was removed from the cyclotron with the original trolley system. The deflector assembly was cleaned and the LCW cooling lines were checked for leaks and some were replaced with new lines. The controls for positioning the deflectors have been restored and the system appears to be functioning properly.

5) **K150 Cyclotron Inflector:** The existing mirror inflector has been removed, cleaned and tested with high voltage and appears to be working properly (off-line). Spare screens and other components are being constructed. During initial startup, the mirror inflector will be used to make the first beams. Once the operation of the central region of the K150 cyclotron is well understood, then a spiral inflector may be introduced.

6) **K150 Cyclotron RF System:** The construction of the RF system was completed in the fall of 2006. It consists of the RF power supplies, control system, RF driver amps, and RF final amplifier.

The control system consists of low voltage power supplies, the modules needed for the RF signal processing, RF driver amplifiers needed to drive the main RF amp, and controls for driving the various machine components relative to the RF system. All the components were built in house and have been tested individually. Spares were built at the same time.

The anode power supply has been built in house. This power supply cabinet provides all the power requirements for the 4CW150,000 power tube used in the final amplifier, as well as the interlock system involved in protecting the power supply, final amplifier, and cyclotron components. The final amplifier tube requires grid, screen, and anode power supplies. The grid and screen power supply chassis are contained inside the main power supply cabinet, and have both been fully tested. In addition, two spares of each have been built. In the summer of 2006, the anode supply was turned on and tested at 150 kilowatts, using the final amplifier as a load. The final amplifier tube was biased on and run at 7.5 amps at 20 kilovolts for 1 hour. The expected temperature rise was seen in the tube cooling water to verify actual power consumption measured at the power supply.

The final amplifier cabinet has been rebuilt with new components and installed on the back of the cyclotron. A filament power supply provides the 15 volts at 200 amps d.c. for the 4CW150,000 tube filament, and was built for us by an outside vendor. A spare supply was also built, and both are compatible with the units used on the K500 cyclotron.

The various machine components pertaining to the running/tuning of the RF system have been repaired as needed and tested for proper operation. Water leaks have been repaired in the resonator panels, as well as associated components involving the movement of the panels. The trimmer drive system has been rebuilt and tested. Now that the cyclotron vacuum system and the new LCW system are functional, the testing of the RF system has begun.

7) **K150 Cyclotron Coil Power Supplies:** All twenty-three coil power supplies have been installed on the cyclotron including the 3000 amp - 180 volt main coil power supply. This supply was placed on the footprint of the original (Ling) main coil power supply which was removed.

8) **K150 ECR & Injection Line:** The design for the injection line was determined by closely following the Berkeley design for their AECR and incorporating the existing elements from our ECR2 injection line. To obtain the highest transmission efficiency possible, two additional focusing elements (Glaser lenses) and one additional set of steering magnets will need to be procured. Power supplies and control equipment for these additional elements will be procured as well. The shape of the hole through the upper center plug has also been redesigned. The original upper center plug cannot be modified since it has retained activity from its years of use. Enough iron has been purchased for both the upper and lower center plugs if rebuilding the lower center plug becomes necessary. Machine work on the new center plug has is nearly complete. All beam line components have been constructed and leak checked. The center plug Glaser lens has been wound including the x-y steering magnets.

Vacuum pressure in the low 10^{-7} torr will be obtained along the entire injection line and into the inflector region with two new external cryopumps and an internal liquid nitrogen cryopanel. The components of the beam line will be joined together using copper conflat seals rather than rubber o-rings. All valves, flanges and cryogenics systems have been received. The internal liquid nitrogen cryopanel is also complete.

ECR2 and its associated equipment have been dismantled from the K500 cyclotron and moved over to the top of the K150 cyclotron. Installation of ECR2 has begun. It is anticipated that the commissioning milestone for the ECR and injection line will be met in early summer 2007 as described in the management plan.

9) **First Beams from K150:** Over the last year, progress has been made on understanding the CYDE program which calculates the cyclotron parameters for a given beam. The original TAMU version of CYDE was lost, but we were able to obtain the code that is currently used at Berkeley for their 88" cyclotron. For $^{7}Li^{2+}$ accelerated to 62 MeV, it is found that the values from this program, which uses the Berkeley field map, agree with the old values from our 88" cyclotron runs from 20 years ago. A set of parameters has been developed for 25 MeV/nucleon alphas and 7.5 MeV/nucleon Argon.

10) **K150 Beam Line:** All magnets, support structures and beam boxes will be built by the cyclotron personnel. All materials needed to fabricate 25 quadrupole magnets, 14 x-y magnets and their support structures have been procured, including insulated copper wire for the magnet coils. All pole and yoke pieces have been machined. The winding and potting of all quadrupole magnet coils has been completed. Early on, two quadrupole magnets made entirely from surplus materials at the lab were completed. Thirteen quadrupole magnets have been completely assembled and are ready for installation. All pieces for x-y magnets have been machined and are ready for assembly. Stands for x-y magnets, quadrupole magnets and beam boxes have been constructed and are assembled. The bid for the beam line magnet power supplies was awarded to Alpha Scientific (same company that built the supplies for the K150 cyclotron coils).

Nine turbo molecular pumping stations will be required for the K150 beam lines. All items needed to build the pumping stations, except the roughing pumps, turbo molecular pumps and their controllers have been received.   The bid for the turbo pumps and mechanical pumps was awarded to Pfeiffer Vacuum Systems. The pumps should arrive in June 2007.

11) **K150 Control System:** A new control system for the K150 cyclotron project has been developed. The new system was developed since the equipment of the current K500 control system is being phased out by industry. A prototype unit using a "Rabbit" brand control card was developed and thoroughly tested by incorporating it into the existing K500 control system and was found to operate the K500 equipment properly. The prototype was also configured to control the new coil power supplies of the K150 cyclotron and was found to operate this equipment properly as well. This new system is both simpler in design and much less expensive compared to the existing K500 control system.

Materials needed to build the new control system have been procured. The new system has been installed and is currently operating twenty-two of twenty-three coil power supplies and is now being developed to read-out the vacuum systems of the K150 cyclotron, beam lines and experimental areas.

TASK 2:

1) **Light Ion Guide:** All materials have been procured including materials for both ion guide chambers, support structure, vacuum pipe, flanges, gas control system and SPIG. The Pfeiffer oil-free Roots1 and Roots2 vacuum systems arrived in May 2006.
2) Ion guide chambers 1 and 2 have been constructed, cleaned, vacuum tested and mounted on the support structure. The internal spark discharge chamber has been fabricated and installed in ion guide chamber 1 and is working properly. All flanges and piping between the Roots1 and Roots2 vacuum systems have been installed. The electrical switch gear needed to power the roots systems and ion guide equipment has been installed. The gas management system has been assembled and attached to the ion guide chamber.

   The Roots1 and Roots2 vacuum systems and gas management systems were checked for proper operation and control. 1+ ions were transferred from the spark discharge chamber to a Faraday cup and the differential pumping system was optimized. Since very large flow will be used in the final design of the light ion guide system, a gas recirculation system is being developed in order to reclaim and reuse the helium gas. To determine the type and level of cleaning system needed, we measured the levels of contaminants in the exhaust of the roots blower. Different systems and pricing are currently being investigated.

   In March 2007, 1+ ions were created in chamber 1 (via spark discharge), transferred into chamber 2 (via differential pumping) and then guided 20 cm through the SPIG device to a Faraday cup positioned at the end of the SPIG. After adjustments to pressure, voltage and RF were made, it was found that nearly 100% of 1+ ions were transported through the 20 cm SPIG device. The SPIG is the device that will transport the radioactive ions from the Light Ion Guide to the CB-ECR ion source.

   The bids for the oil-free Roots 3 blower and turbo molecular vacuum systems have been awarded to Pfeiffer Vacuum. These systems are required for the final differential pumping system that will connect the Light Ion Guide system to the CB-ECR IS.
3) **Beam Dump and Radiation Shielding:** The design for the beam dump and shielding structure has been completed by using the modeling codes obtained (PHITS, MORITZ and MCNPX). A review panel made from outside experts approved the design during a visit in March 2007. The panel consisted of Reg Ronningen (NSCL), Igor Remec (ORNL) and Don Cossairt (FNAL). A materials list for the beam dump has been compiled.
4) **Heavy Ion Guide:** The collaboration with the ANL gas cell group is in continuation. Plans go as follows:
   - Measure main parameters (isotopic yields, energy and space distributions) of secondary species at the K150 beam energies with Big Sol at Texas A&M
   - Test the efficiency of the heavy ion gas cell at ANL at high input densities (similar to the gas cell we are planning to build at Texas A&M)
   - Reassemble the gas cell at GSI including:
     a. Install thermo-resistant insulation and sealing ceramic rings
     b. Install oil-free roots blower system
     c. Test the cell off-line to prepare for an experiment on the FRS (time of the experiment at the GSI is under discussion)

TASK 3:

1) **CBECR Ion Source:** SBIR Phase 2 funding was awarded to Scientific Solutions to build a CB-ECRIS. Once completed, this CB-ECRIS will be installed at the Cyclotron Institute. The SBIR project schedule has been determined to be 18 months and should be delivered in August 2007 which matches well the schedule for the Upgrade Project. It has been estimated that ~$250k of major equipment will need to be supplied by the Cyclotron Institute to complete the CB-ECRIS. This will include turbo molecular pump systems, coil power supplies, microwave transmitters and control equipment.

   The construction of the CB-ECRIS by Scientific Solutions is proceeding on schedule. The bid for the two sets of turbo molecular and mechanical pumps was awarded to Pfeiffer Vacuum. The pumps were received in March 2007 and delivered to Scientific Solutions.

2) **n+ Transfer System:** The design for the n+ transfer system that will connect the CB-ECR IS to the K500 cyclotron has been completed. All solenoids and x-y steering magnets will be built by in-house personnel. The 90^{o} bending magnets will be built through a collaboration with the NSCL and the Cyclotron. Construction will follow the recent design made by the NSCL which will improve transmittion efficiency over the current design. The Cyclotron will build the coils and NSCL will build the yokes and vacuum chambers. Two complete magnets are needed by each laboratory and should be completed in the summer of 2007. The list of materials and power supplies needed to complete the beam line is being compiled.

   High vacuum will be maintained at low 10^{-7} torr with several cryopump stations and all connections along the beamline will be made with conflate flanges and copper seals. Diagnostic stations will also be installed along the beam line.