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Argonne CW Linac (ACWL) -- Legacy from SDI and Opportunities for the Future*

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Abstract. The former Strategic Defense Initiative Organization (SDIO) invested significant resources over a 6-year period to develop and build an accelerator to demonstrate the launching of a cw beam with characteristics suitable for a space-based Neutral Particle Beam (NPB) system. This accelerator, the CWDD (Continuous Wave Deuterium Demonstrator) accelerator, was designed to accelerate 80 mA cw of D^- to 7.5 MeV. A considerable amount of hardware was constructed and installed in the Argonne-based facility, and major performance milestones were achieved before program funding from the Department of Defense ended in October 1993. Existing assets have been turned over to Argonne. Assets include a fully functional 200 kV cw D^- injector, a cw RFQ that has been tuned, leak checked and aligned, beam lines and a high-power beam stop, all installed in a shielded vault with appropriate safety and interlock systems. In addition, there are two high power (1 MW) cw rf amplifiers and all the ancillary power, cooling and control systems required for a high-power accelerator system. The SDI mission required that the CWDD accelerator structures operate at cryogenic temperatures (26K), a requirement that placed severe limitations on operating period (CWDD would have provided 20 seconds of cw beam every 90 minutes). However, the accelerator structures were designed for full-power rf operation with water cooling and ACWL (Argonne Continuous Wave Linac), the new name for CWDD in its water-cooled, positive-ion configuration, will be able to operate continuously. Project status and achievements will be reviewed. Preliminary design of a proton conversion for the RFQ, and other proposals for turning ACWL into a testbed for cw-linac engineering, will be discussed.

INTRODUCTION

The Continuous Wave Deuterium Demonstrator (CWDD), a cryogenically-cooled ground-based accelerator facility, was being built to test components and concepts for a space-based Neutral Particle Beam (NPB) system. The CWDD research and development program was set up to pursue four main objectives: cw operation, deuterium (D^-) beams, operation at cryogenic temperatures, and high beam brightness. The CWDD accelerator included a D^- ion source, cw RFQ and a cw ramped-gradient drift-tube linear accelerator (RGDTL). Grumman Aerospace Corporation, the prime contractor, had overall system responsibility. Culham Laboratories UK was a major subcontractor for the injector, beam lines, diagnostics and controls and Los Alamos National Laboratory assisted with design, prototyping and cold-model testing. Site, services, and cryogenics were being provided by Argonne National Laboratory, and CWDD was to be turned over to Argonne for ongoing programs upon demonstration of compliance with contract specifications. CWDD was being installed and commissioned at Argonne when the NPB program was cancelled in October 1993, and subsequently was turned over to Argonne "as is".

Presently, the facility is being maintained in its nearly-completed state while we consider modifications to the accelerator and beam stop to prepare it for new missions and sponsors. All plans for cryogenic operation have been dropped; we will instead change to water cooling and will operate the structures at room temperature. This change removes both the expense of a

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cryosystem and its operating-time limitation (as designed, CWDD would have required over one hour to lower the refrigerant temperature from 30K to 26K after 40 seconds of full-power cw operation). The name "CWDD" is strongly associated with both the previous mission and operational parameters; these are now changing and to mark these changes, a new name, the Argonne Continuous Wave Linac (ACWL) has been adopted for the facility. Thus, we will use "CWDD" when referring to the original design goals and what was accomplished prior to the NPB program termination, and "ACWL" when discussing future plans and proposals.

We are proposing to use ACWL to generate engineering and operational data relevant to the high-current cw accelerators being proposed for spallation neutron sources (the Los Alamos' proposals that have made "Axy" a generic term for intense cw proton linacs[1], the Japanese OMEGA program[2] etc.) and the fusion community's International Fusion Materials Irradiation Facility (IFMIF)[3]. We also propose to use the ACWL beam with a low-Z target and moderator/collimator to generate neutron beams for neutron radiography (NR) or boron neutron capture therapy (BNCT), believing that such a dual use of the facility reaps maximum benefit from the assets and shares operating costs between two or more sponsors.

THE CWDD PROGRAM - DESIGN AND ACCOMPLISHMENTS

General

A schematic layout of the CWDD facility is shown in Figure 1. With the exception of the RGDTL, all items and subsystems shown have been installed and most have been commissioned or are awaiting final hookup to cooling or power. Funding constraints postponed acquisition of the 150,000 standard cubic feet of neon (required to commission the cryo refrigerator) in FY93, which as a consequence prevented high-power operation of the RFQ. Low-power operation could have started late in FY93, but to do so would have interrupted the schedule for high-power operation. By the time such a schedule change could have been considered (when it was apparent that the CWDD program would not be funded for completion) the opportunity had passed.

200 keV D^- Injector

The CWDD injector, designed and built at Culham Laboratory, comprises a volume ion source, triode accelerator, high-power electron traps and low-energy beam transport (LEBT) with a single focusing solenoid.[4] The injector control systems were designed to produce beam pulses variable from a few microseconds to 20 seconds (consistent with the beam requirements of the accelerator as a whole). However, the source is capable of continuous (dc) operation and was operated briefly in dc mode to deliver more than 20 mA of D^- to a beam stop in the LEBT line. It is expected that the D^- current could be doubled by adding cesium to the source.[5] However, with no further requirement to demonstrate neutral-beam capability, operation can be simplified and current capability significantly increased by changing the source to deliver D^+.

CWDD FACILITY

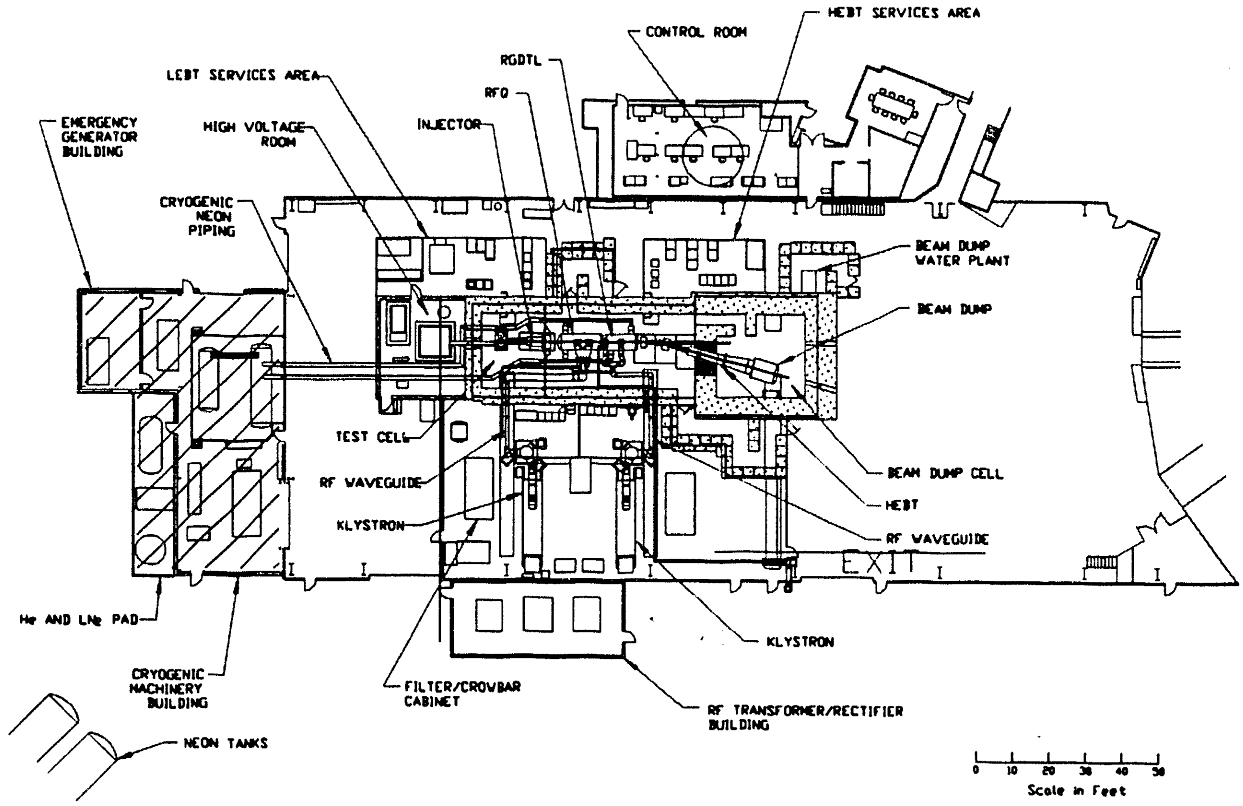

Fig. 1. CWDD Facility layout showing key accelerator components, shielded vault and ancillaries.

2 MeV CW Radiofrequency Quadrupole Accelerator (RFQ)

The RFQ is a four-meter long rf cavity, made by assembling four one-meter long segments. The segments are made from solid tellurium copper, machined and then electroformed into a four-vane configuration. The RFQ has extensive internal cooling channels and all ancillary components (tuners, rf power couplers, end walls) are actively cooled. RF power dissipation at design fields at room temperature is 600 kW. The RFQ has been installed in its cryostat (which also serves as the vacuum chamber), and has been aligned with the injector and exit beamline, and connected to the rf drive lines. It is presently connected to the cryo refrigerator, but those lines will soon be removed to prepare for water cooling.

7.5 MeV CW Ramped-Gradient Drift Tube Linac (RGDTL)

Deuterons were to be accelerated from 2 MeV to 7.54 MeV in a 47 cell RGDTL in which the fields were ramped from 2.0 to 4.0 MV/m over its 2.6 meter length.[6] The 46 drift tubes have been assembled and leak checked, and the tank has been machined, but no work has started on the vacuum chamber (cryostat) or end flanges.

RF Power Systems

The 352.2 MHz rf power systems were designed and manufactured by GE Marconi Communications Systems Ltd and comprise two 1 MW cw klystron amplifiers (to power the RFQ and RGDTL respectively) and a 25 kW tetrode amplifier (for the matching section cavity between the RFQ and RGDTL). All three amplifiers are complete and installed, and two (the tetrode amplifier and the triode amplifier for the RFQ) have been commissioned into resistive loads. The tetrode has operated to full power; but problems with the 1 MW load for the klystron amplifier limited cw operation to 550 kW.

Controls, Diagnostics, Ancillary Subsystems

Most of the control and diagnostics systems are completed and major parts, such as the injector/LEBT controls and diagnostics, the PASS (personal access safety system), fire and radiation protection systems etc., have been in service now for over two years. The water cooling systems are completed and in service, except for connections between the pump station and the RFQ.

ACWL - PLANS AND PROPOSALS

Completion Choices

Commissioning plans for the RFQ were well advanced when the NPB Program was cancelled, but only parts of the RGDTL had been fabricated. We have consequently deferred planning for the RGDTL, and have been concentrating on completing the RFQ as a water-cooled cw structure and on adding a neutron-producing target and moderator to produce neutron beams suitable for neutron radiography (NR) and/or boron neutron capture therapy (BNCT). Making dual or multi-use of the facility (operating the accelerator to extract cw engineering, reliability and control data while also using the beam for target studies, radiography or therapy) would split operating costs between sponsors, providing maximum return at minimum cost.

The proposed change to water cooling is greatly facilitated by the fact that the original plans for CWDD called for both water and cryo cooling; water cooling for initial full-power cw rf conditioning of the structures and then cryo cooling to 26K for accelerated-beam operation. Later in the program, tests at Grumman[7] established that cw structures could be successfully conditioned at cryo temperatures. However, by then most of the major components had been designed or were being built and were not changed to take advantage of the lower power dissipation and improved thermal conductivity that comes from cooling the structures to 26K. The exception for the RFQ was with the rf drive-line windows, which are Rexolite© disks and were only tested to 70 kW. These will almost certainly not be suitable for the 200 kW required for room temperature operation. That a solution is possible is shown by the successful operation of a cylindrical alumina window[8] at >225 kW on the Chalk River cw RFQ[9]. A similar design could be adopted for ACWL if the simple replacement of the Rexolite disks by low-loss alumina disks proves insufficient.

The CWDD RFQ will accelerate a deuteron beam (either D^- or D^+) to 2 MeV. The present D^- source limits the available current to about 20 mA. However, this source could be converted for D^+ operation[10] to provide the design 90 mA input current for the RFQ that will give 80 mA of 2 MeV deuterons. Such a beam, impinging on a thick beryllium target, should give about 6×10^{13} n/s, the same production rate as obtained with the same current of 3.5 MeV protons on a beryllium target or 2.5 MeV protons on a lithium target.[11] Beam power (and hence target cooling problems) varies with energy, and since the melting point for beryllium is 1280°C, while that of lithium is only 186°C, target engineering would appear to favor Be(d,n). However, the maximum neutron energy is less with protons (1.6 MeV for Be(p,n) and 0.8 MeV for Li(p,n) for the proton energies above), and are therefore more efficiently moderated to obtain the thermal neutrons wanted for NR or the epithermals wanted for BNCT. Thus the choice of proper beam and target is not just a question of yield, but also depends on neutron energy and the thermo-mechanical properties of the target. Unfortunately, there is a distinct paucity of data in all these areas for 2-5 MeV deuterons or protons on low-Z targets. The MCNP transport code is being used to estimate the yield of thermal and epithermal neutrons for different moderator materials and the beam/target combinations discussed above. We do not expect definitive answers because of uncertainties (factors of 2 to 4 in some instances) in yield, energy and angular distribution for these beam-target combinations,[12] but hope for some indication of the trade-offs between higher neutron yield (deuteron beams) and lower neutron energy (proton beams).

We are also looking at the possibility of modifying the CWDD RFQ to produce a 2.5 or 3.5 MeV proton beam should this be necessary. Calculations[13] with the RFQUIK and PARMTEQ codes show that by merely changing the vane profile (and without exceeding the 1.8 Kilpatrick design field of CWDD), the RFQ could be modified to accelerate over 75 mA of protons from 75 keV to at least 3 MeV. Such a change would expand the range of data that ACWL could provide for programs like Axy. An RFQ can in general be used to accelerate particles of a smaller mass-to-charge ratio, but the output velocity of a fixed-frequency RFQ is constant, so without modification, a 2 MeV deuteron RFQ will only accelerate protons to 1 MeV. To get higher-energy protons, the tip geometry would have to be changed. Such a modification (building up the tip by electroforming and machining a new profile) was performed on one section during the original manufacturing process[14], however based on original manufacturing times, the electroforming for reassembly after machining would keep the RFQ out-of-service for at least one year. There is a lot of engineering data, relative to either a proton or deuteron linac, that can be obtained from CWDD in its original configuration. Therefore, even if an eventual change to protons becomes necessary, we envisage starting operation with deuterons and doing a shutdown to modify for protons after obtaining this data.

Staged Program

CWDD was being built to a very ambitious schedule to generate engineering data (demonstrate cw-cryo operation and a D^- beam that would be suitable for an NPB system) for a soon-to-follow space experiment. The cancellation of the NPB program does not remove the requirement for the type of data CWDD (now ACWL) can generate. In fact, such data is even more critical for "Axy" or IFMIF accelerators because the economics and practicality of such systems are tightly tied to the lifetime and dependability of the basic accelerator components. To be viable, an IFMIF or Axy must provide very high availability (90% or greater) over many years. Thus the requirement for such data is still there, but the time frame is not as tight as neither appear likely to receive major funding for several years. Consequently we are proposing a more extended program for ACWL than had been followed for CWDD, one that is more affordable, that can generate the longer-term data relevant to Axy, and that can evolve as such data is accumulated. Although deuterons are of primary interest for IFMIF, it is likely that for Axy and for either NR or BNCT neutron source development, that ultimately a change from deuterons to protons will be warranted. First however, benefit should be taken of the potentialities of the nearly completed deuteron linac, so an ACWL program will probably extend over four or more years. For an assumed dual mission of engineering development for Axy and development of a high-resolution neutron radiography facility, the program highlights and types of information that could be obtained for the Axy mission could be as follows (with major NR mission milestones in italics to show how the two missions are harmonized):

Year One

- commission water cooling for RFQ and condition RFQ to design cw power
- obtain information on stability of a 4 meter long cw RFQ, information on multiple rf drive loops (4) and on sparking rates and spark damage in a long RFQ (stored energy a factor of 4 greater than Chalk River RFQ1[15])
- *{design NR beryllium target and neutron moderator/collimator}*

Year Two

- commission RFQ accelerator and get operating experience with 20 mA D^- beam
- continue accumulating operating data with 1 MW cw rf amplifier
- complete design modifications to the injector to permit change from D^- to D^+
- *{fabricate and install NR target and obtain first beam-on-target results}*

Year Three

- complete design of modifications to RFQ for change from deuterons to protons
- gain RFQ operational experience with >50 mA deuteron beam
- commission proton injector and begin injector long-term-reliability tests
- *{commission NR moderator/collimator and demonstrate production runs with industrial products}*

Year Four

- modify RFQ for protons, install and commission
- continue proton injector long-term-reliability testing
- accelerate >75 mA cw proton beam in RFQ
- *{complete design and confirm performance predictions for accelerator-based NR facility}*

CONCLUSIONS

SDIO, through the U.S. Army Space and Strategic Defense Command (SSDC), invested significant resources in the CWDD facility prior to cancellation of the NPB program. This nearly-operational facility is now available for other missions, and offers a very cost-effective means of obtaining critical cw linac engineering and operational data.