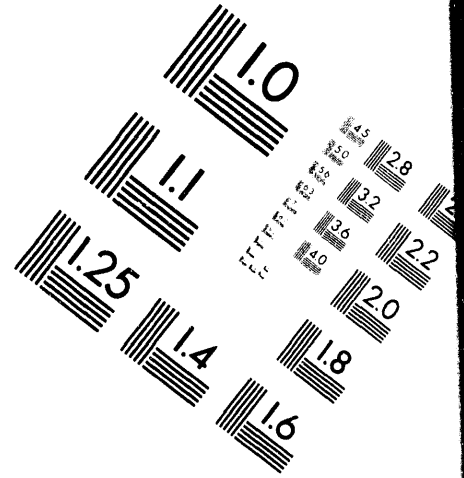
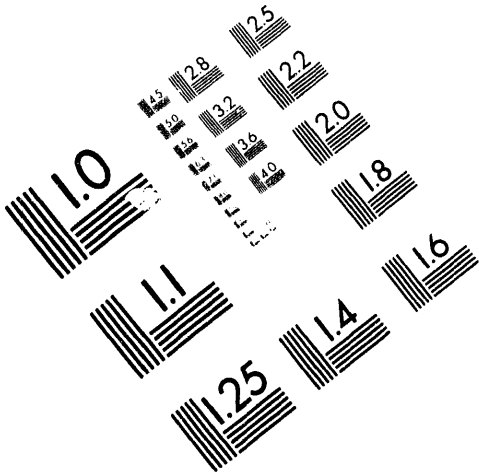




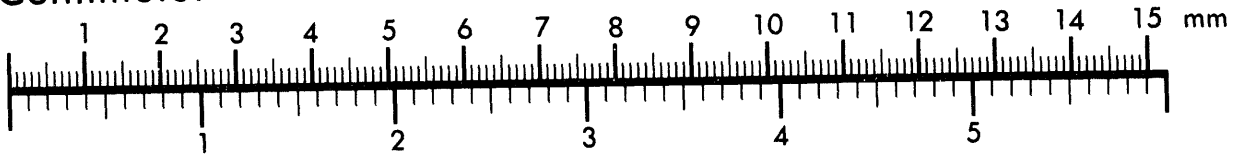
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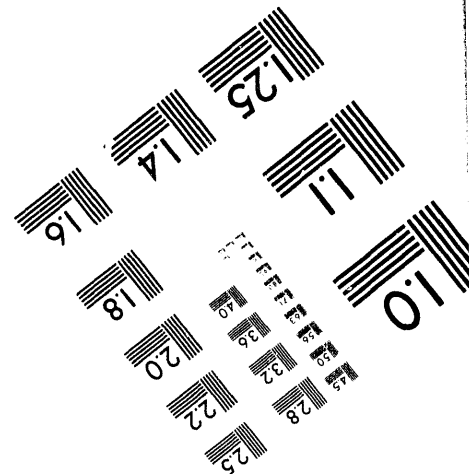
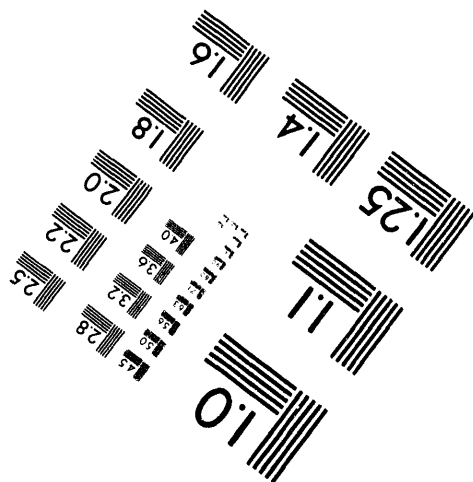
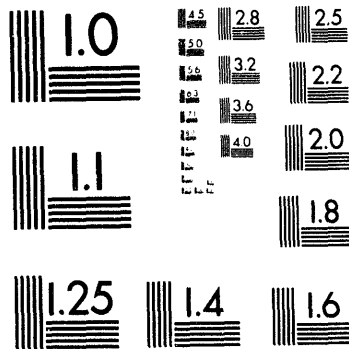
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## CWDD ACCELERATOR AT ARGONNE -- STATUS AND FUTURE OPPORTUNITIES<sup>†</sup>

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### Abstract

The Continuous Wave Deuterium Demonstrator (CWDD) accelerator, a cryogenically-cooled (26K) linac, was designed to accelerate 80 mA cw of D<sup>-</sup> to 7.5 MeV. CWDD was being built to demonstrate the launching of a beam with characteristics suitable for a space-based neutral particle beam (NPB). A considerable amount of hardware was constructed and installed in the Argonne-based facility, and major performance milestones were achieved before program funding ended in October 1993. Existing assets have been turned over to Argonne for continuation under other sponsors. These include a fully functional 200 kV cw D<sup>-</sup> injector and high power (1 MW) cw rf amplifier, a cw RFQ that has been tuned, leak checked and aligned, and a partially completed ramped-gradient DTL. Project status and achievements are reviewed and proposals for future use of the equipment are discussed.

### Introduction

The CWDD research and development program was set up to pursue four main objectives: cw operation, deuterium (D<sup>-</sup>) beams, operation at cryogenic temperatures, and high beam brightness. The CWDD accelerator included a 200 keV dc D<sup>-</sup> injector, and two cw structures: a 2 MeV radiofrequency quadrupole (RFQ) and a 7.54 MeV ramped-gradient drift-tube linear accelerator (RGDTL). Grumman Aerospace Corporation, the prime contractor, had overall system responsibility. Culham Laboratory 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 Argonne was to have responsibility for ongoing programs upon demonstration of compliance with contract specifications. Following the cancellation of the NPB program in October 1993, CWDD was turned over to Argonne "as is".

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. Plans for cryogenic operation have been dropped; the rf structures will be water cooled and will operate at room temperature. This change removes both the expense of a 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[1], [2] and the International Fusion Materials Irradiation Facility (IFMIF)[3]. We also plan to install a low-Z target and moderator/collimator to generate neutron beams for neutron radiography (NR) or boron neutron capture therapy (BNCT).

### CWDD - Design and Accomplishments

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.

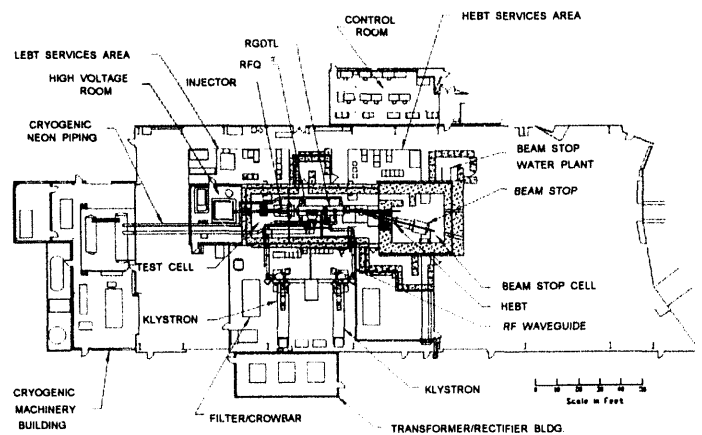


Fig. 1. CWDD Facility layout.

### 200 keV D<sup>-</sup> Injector

# MASTER

The CWDD injector, designed and built at Culham Laboratory, comprises a volume ion source, triode accelerator,

<sup>†</sup>This work was performed under the auspices of the U.S. Department of Energy.

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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<sup>-</sup> to a beam stop in the LEBT line. It is expected that the D<sup>-</sup> current could be doubled by adding cesium to the source.[5]

## 2 MeV CW RFQ

The RFQ is a four-meter long rf cavity, made by assembling four one-meter long segments.[6] The segments are made from solid tellurium copper; for each segment, four vane/quadrant sections are finish-machined and then assembled by electroforming into a pseudo-monolithic structure. 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 544 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. The matching section, to provide the longitudinal and transverse match between the RFQ and RGDTL, has been completed and installed. The previously-installed cryo-refrigeration lines have been removed and connectors for water cooling are being installed.

## 7.54 MeV CW 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.[7] The 46 drift tubes have been assembled and leak checked, the tank, end walls and post couplers have been machined, but no work has started on the vacuum chamber (cryostat).

## 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 and one klystron amplifier) 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 have been fabricated. We have consequently deferred planning for the RGDTL, to concentrate on completing the RFQ as a water-cooled cw structure and on adding a neutron-producing target and moderator for NR or 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) will make optimum use of the facility and divide operating costs between sponsors.

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[8] established that cw structures could be successfully conditioned at cryo temperatures. However, by then the major components had been designed or were being built and, with one exception, 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 involved the RFQ rf drive-line windows, where Rexolite® disks were used in place of alumina. The Rexolite windows were only tested to 70 kW and will not be suitable for the  $\approx 170$  kW per window (structure + beam) required for room temperature operation. A cylindrical alumina window[9] operated at  $>225$  kW on the Chalk River cw RFQ[10], and a similar design can be adopted for ACWL if replacement of the present Rexolite disks by low-loss alumina disks proves insufficient.

The CWDD RFQ will accelerate a deuteron beam (either D<sup>-</sup> or D<sup>+</sup>) to 2 MeV. The present D<sup>-</sup> source limits the available current to about 20 mA. However, this source can be converted for D<sup>+</sup> operation[11] to provide the design 90 mA input current required by the RFQ to give 80 mA of 2 MeV deuterons. Such a beam, impinging on a thick beryllium target, should give about  $6 \times 10^{13}$  n/s, the same yield as with like current of 3.5 MeV protons on beryllium or 2.5 MeV protons on lithium.[12] Beam power (and hence target cooling problems) varies with energy, and as 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 NK 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[13], 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. Although an RFQ can in general be used to accelerate particles of a smaller mass-to-charge ratio, because the output velocity of a fixed-frequency RFQ is constant, as built the RFQ will only accelerate protons to 1 MeV. To get higher-energy protons, the tip geometry will have to be changed. Calculations with the RFQUIK and PARMTEQ codes show that by 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 the proposed spallation neutron sources and the modification technique (building up the tip by electroforming and machining a new profile) was demonstrated on one section during the original manufacturing process[14]. Based on original manufacturing times, the electroforming for reassembly after machining would keep the RFQ out-of-service for at least one year. However, there is a lot of engineering data, relative to either a proton or deuteron cw linac, that can be obtained from the present RFQ and so our first intention is to commission it with deuterons.

### Conclusions

Following termination of the NPB program, this nearly-operational facility is now available for other missions. It offers a very cost-effective means of obtaining critical cw linac engineering and operational data and could be a valuable testbed for accelerator-based NR or BNCT development.

### Acknowledgments

The "CWDD Technical Team" included physicists, engineers and technicians from Grumman Aerospace Corporation, Culham Laboratory, Los Alamos National Laboratory and Argonne. Their efforts are gratefully acknowledged, and it is hoped that those efforts will be rewarded through the completion of the facility and the verification that it "meets specifications". However, it also takes another group to accomplish a program like CWDD, and the authors would like to acknowledge the efforts of Dr. M. Lavan and his group at SSDC. They conceived the program, kept it on track through several turbulent years, fought hard for its completion and continue to lend their support to our efforts to redirect it.

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