Report of the CBETA Advisory Committee

February 22/23 2018, Ithaca, New York

Committee Members

Sergey Belomestnykh (Fermilab), Oliver Brüning (CERN), Wolfram Fischer (BNL), Mike Harrison (BNL, Chair), Shinji Machida (Rutherford), David Rubin (Cornell).

Format

The review consisted of a day of plenary sessions followed by a short Q/A session and an executive session on the final day for the preparation of the Committee's close-out. The meeting agenda is given in Appendix 1.

The Charge for the review is given in Appendix 2. There were some general questions in the preamble to the Committee together with five specific charge elements. The Committee's responses to these questions and charges are given below together with comments and recommendations.

Responses

1) Preamble "The CBETA project is in contract with NYSERDA to build a four-pass Energy Recovery Linac. The Advisory Committee is asked to report to the CBETA Oversight Board on whether the project will be able to deliver the parameters listed in Table 1, on a schedule with the high level technical milestones shown in Table 2, and to offer advice on ways that the probability of technical success can be improved. "

Response: *The Committee considers that the Key Performance Parameters (KPPs) are achievable in a time period consistent with the commissioning plan. We believe the most challenging* ***design*** *parameter will be the high current which introduces many additional complications, and may well require instrumentation beyond the base line. Realizing the design energy requires establishing four passes through the FFAG return arc, which will represent a major technical achievement in itself. The impressive simulations and modeling indicate that the factor of 4 energy gain can be achieved with careful commissioning and orbit and optics correction.*

The construction and commissioning schedule is plausible, with the biggest uncertainty being the delivery of components, especially splitter magnets and return arc girders. The infrastructure for the Fractional Arc Test (FAT) is presently well advanced with timely completion in the hands of the splitter magnet supplier. Should these magnets arrive as expected, in the near future, then the GO/NOGO milestone of the FAT in April is feasible. The project should continue to stay in close communication with vendors in order to ensure timely delivery of components.

Recommendations:

- *The Committee is concerned that the instrumentation is somewhat constrained by the density of the component layout. We suggest a review of essential instrumentation requirements and potential possibilities for future enhancements.*

- *The start of the girder installation signals a new phase of the project. Communication and consensus among the technical teams is essential to ensure that the effort is well coordinated with attention to such elements as temperature stability, power requirements, assembly sequence, etc.*

2) Main Linac Cryomodule: (examine the) issues and solutions identified and addressed in the testing, that has already been performed with and without beam, including microphonics and the need to reliably accelerate or decelerate the beam by 36 MeV on each pass.

Response: *The major issues have been identified. They are: large microphonic noise, especially on the three unstiffened cavities; and potential infant mortality of the solid state amplifier (SSA) components. Solutions for the microphonics issue have been proposed and a plan is in place. The potential infant mortality will be revealed (and fixed as necessary) during an extended test of the solid-state amplifiers. After these two major issues are addressed, MLC should be able to reliably accelerate/decelerate the beam by 36 MeV per pass.*

Comments: *Large microphonic noise on the unstiffened cavities in the MLC remains a major concern for stable operation of CBETA. Sources of the microphonic noise (thermo-acoustic oscillations, noise from the pumping skids, JT valve actuation) were identified during recent tests. A mitigation plan is in place, but still has to be implemented and the noise level re-measured. The expectation is that this will allow an MLC energy gain of 58 MeV, which should provide sufficient margin for reliable operation at 36 MeV.*

So far, the MLC cavities were only tested individually since only a single prototype 5-kW SSA was available. Simultaneous operation of all six cavities with the required field stability and minimum energy gain (36 MeV) still has to be demonstrated.

Infant mortality of components of the just delivered SSAs is another major concern. While the amplifiers have been factory-tested, the test time was short.

Recommendations:

- *Implement the microphonics mitigation plan to ensure stable and reliable operation of the MLC with beam at a 36 MeV energy gain.*
- *Perform an extended test of all six SSAs as soon as possible.*
- *Test simultaneous operation of all MLC cavities and demonstrate the required field stability at and above the minimum required MLC energy gain.*

3) Halbach magnets and girders: magnet quality, arc production, integration and installation, consistent with technical milestones 7 and 8 ("Girder production run complete" and "Final assembly and pre- beam commissioning complete").

Response: *The Halbach magnet field quality has been demonstrated and magnet production is underway. Girders have been designed and their production is about to begin. A single protoype girder has been delivered for the FAT. The progress to date, and the production, integration and installation plans, are consistent with technical milestones 7 and 8.*

Comments: *The Committee feels that the prototype girder has validated the fundamental concept of permanent magnets. It is now a proven technical solution. In particular, the Committee is impressed by the field shimming, which indicates that a single tuning iteration will in most cases produce the desired field quality. In addition, the team demonstrated that a magnet can be repaired if necessary.*

All indications suggest that the vendors will meet the production targets and BNL can produce one (or more) girders per week. So far, all of the components have met their specs (mechanical tolerances, magnetization).

It remains to be demonstrated that alignment will be maintained during shipping from BNL to Cornell. However, the Committee thinks that this should not be an issue.

The Committee notes that while the vendor for splitter magnets has a proven track record in Europe, CBETA has not yet received any production magnets. Delivery of the first set of splitter magnets is critical for the FAT.

Recommendations:

- *The Committee notes that for the foreseeable future the girders and magnets will remain as a critical path project element. The team should pay close attention to the delivery and assembly schedule. If possible, the production should be sped up.*

4) Commissioning strategy: milestones 9, 10 and 11, which outline a beam commissioning path that meets the key performance parameters. Alternative commissioning strategies under consideration could be more efficient, and could be implemented after the Fractional Arc Test in early 2018.

Response: *The Committee understands that a factor of 2 energy acceptance cannot be technically demonstrated with a single pass. As an alternative, the demonstration of a broad energy acceptance of the FFAG lattice (milestone 9) is proposed after the demonstration of the single pass energy recovery (milestone 10). The Committee members disagreed on whether the single pass or broad energy acceptance requirement in milestone 9 should be modified. We did agree however that this milestone needs to be reworded.*

Comments: *The Committee agrees that the demonstration of a factor 2 energy acceptance can only be achieved with a second pass, which could follow the demonstration of milestone 10.*

The new proposal also has the potential for earlier demonstration of the KPPs.

An energy scan within a small momentum range of a few percent will be necessary during commissioning in order to maximize the beam transmission through the FFAG return arc. More than 99.9% transmission is needed for the energy recovery mode. It is difficult to predict and set the energy for the best transmission given that there are a couple of nonlinear resonances in the tune space near the footprint of the 42 MeV beams out of the MLC. There are inevitably some gradient errors as well.

It was unclear to the Committee how the transmission of 99.9% can be assured given the planned instrumentation. Proper diagnostics to detect the beam current before and after the return arc and/or a strategy of beam collimation, if it is planned, should be discussed.

After energy recovery has been achieved, demonstrating the factor 2 in momentum acceptance may require very little effort, once the S-1 beamline has been repositioned, and likely provides more time for the demonstration of 4-pass operation. Timing of the vacuum break, needed to reposition the S-1 beamline, is then clearly defined after the single pass energy recovery, which would be summer in 2019.

Recommendations:

- *Reword milestone 9*

- *Alternative commissioning scenarios should be developed for implementation if lower transmission efficiencies are encountered. Compared to the ATF test, the CBETA lattice has new optics features such as the adiabatic transitions from arcs to straights, and one should be prepared for the unexpected. An energy scan is an obvious tool to investigate transmission problems; the equivalent to a tune scan in ordinary accelerators.*

5) Beam tests and studies: results of beam tests made during "Injector CryoModule", "Main Linac Cryomodule" and other running periods. Please also evaluate and advise on low and high current beam dynamics studies and simulations designed to inform component design (eg Halbach magnets, instrumentation, impedances) and to prepare for beam commissioning (eg closed orbit correction).

Response: *Tests performed to date demonstrate that with tuning, the injector delivers beam of sufficient quality for the FAT. We encourage the commissioning team to continue developing functionality of CBETA-V to include analysis of beam response measurements to make optimization of beam parameters more deterministic. The measured and simulated beam profiles still show differences that will likely become important for high intensity operation, in particular the shape and formation of the beam halo. A better understanding of the origin of the beam halo might be desirable for high beam intensity operation.*

Comments: *We see impressive progress in simulation of dynamics with models that include field errors and misalignments. The tolerances revealed by the simulations are indeed being used to formulate specifications for magnet field errors, temperature stability etc. It is important to include BPM errors in these simulations and to look at the required temperature stability for the BPM electronics.*

The Committee encourages the team to think about potential additional diagnostic tools, software as well as hardware, that could help in understanding the beam dynamics when the operation moves from the low intensity, single pass operation to high intensity operation with multiple re-circulations and energy recovery. CBETA will be a 'one of a kind' new machine at this stage and having a powerful and flexible beam diagnostics system available will be a pre-requisite for understanding and testing the limits of CBETA in this unchartered territory.

To this end, it is also important to think early on about potential locations for the installation of such additional equipment in the CBETA machine.

In particular, the Committee encourages the CBETA team to define a prioritized list of additional beam diagnostics tools that could be digested and discussed with potential international partners. The Committee feels that a more transparent discussion within the project and a common agreement on the prioritization is still missing in this process.

Interpretation of diagnostic instrumentation will typically depend on sophisticated analysis of the data. The CBETA-V program is well structured to incorporate tools for real time analysis of beam measurements, and the Committee recommends its continued development. In addition, orbit, optics, emittance correction, and routine tuning should be automated in order that beam studies proceed most efficiently and effectively.

Recommendations:

- *Define a prioritized list of additional beam diagnostics tools that could be installed in CBETA in potential future upgrades and identify potential locations in the machine for their installation.*

6) International Collaboration

(Assess) Opportunities for cost-neutral collaboration especially during the NYSERDA CBETA construction phase. Potential later phases might extend the BNL-CU collaboration, and might include additional institutions.

Response: *There are several international projects with similar, yet complementary scope as the CBETA project. The most noteworthy projects in this category include: bERLinPro, a high current single pass ERL that has a commissioning schedule similar to CBETA; PERLE, a planned multi-turn high current facility planned in France that is still in its starting phase; and MESA, a low current multi-turn ERL that is in its construction phase.*

Comments: *The Committee recognizes that connections between CBETA and these projects do exist already to some extent, but encourages the CBETA team to strengthen further and perhaps organize these collaborations more formally. The Committee is convinced there are many potential benefits from a closer collaboration with international partner laboratories ranging from the exchange of commissioning experience to the exchange and development of diagnostics tools.*

In the UK, the underpinning R&D programme for future UK XFEL is under way. The options of a recirculating linac, possibly with energy recovery, are being evaluated to provide high repetition rate capabilities. Considering the expertise and knowledge from legacy ERL/FFAG projects (ALICE/EMMA) and possible application to future XFEL machine, there is a strong interest in the UK to participate in the CBETA project.

Another part of the UK accelerator community is interested in the full understanding of accelerators with fixed field magnets. Between 2007 and 2013 the UK spent considerable effort and developed significant skill base on the EMMA project and is now giving careful consideration to a similar type of machine as a part of the design for a successor to the ISIS short pulse spallation neutron source (probably post 2030).

It is clear that UK involvement in the CBETA project in the construction and commissioning phase is mutually beneficial and has already been established in form of an exchange of staff for short time period (a few weeks). This should continue and even be extended to more long term involvement in the coming years.

Recommendations:

- *The Committee recognizes that first steps in search for potential future users for the CBETA facility have started. The Committee encourages these steps. A user community could help in obtaining funding for an extended operation of CBETA beyond the achievement of the initial design goals. Starting this process now is extremely timely as a program and funding will need to be identified within the next year or two.*

- *CBETA is a 'first of its kind' machine where one would wish to have the maximum tool set possible at hand to fully study and understand this new type of machine. To this extent it would be interesting to explore options for additional diagnostics tools through international collaborations [e.g. the gas curtain monitor developed by Liverpool University for single pass transverse beam profile measurements]. In this context it would be helpful to prepare a prioritized list of tools [e.g. measurement of intra-bunch structures] and to explore possible implementations for such devices with international partners.*

- *The formation of an international ERL Collaboration Network might be an interesting option for strengthening the international collaboration and identifying a potential user community. Such a setup could also help in attracting additional third party funds for the full exploitation of the CBETA facility. The application for additional operation funds in the framework of the future electron Ion collider development is an excellent initiative in this direction which could be integrated within the formation of an international collaboration framework.*

Appendix 1 – Meeting Agenda

Cornell University, Wilson Laboratory, Room 374.

			Charge #
Thursday, February 22, 2018			1 2 3 4 5
7:40	Van pickup from Hilton Garden Inn & Hotel Ithaca		
8:00	Executive session		
8:30	Project status	Steve Peggs	x x x x x
9:30	Accelerator Physics	Georg Hoffstaetter	x
10:00	High Level Controls	Colwyn Gulliford	x
10:30	**COFFEE BREAK**		
10:45	Return arc optics	Dejan Trbojevic	x
11:15	Halbach magnet physics	Stephen Brooks	x
11:45	Halbach magnet system	Joe Tuozzolo	x
12:15	**LUNCH in-situ for the panel**		
13:00	RF Systems	Peter Quigley	x
13:30	Main Linac Cryomodule	Nilanjan Banerjee	x
14:00	Splitters	David Burke	x
14:30	**COFFEE BREAK**		
14:45	BPM system	Rob Michnoff	x
15:15	Instrumentation	John Dobbins	x
15:45	Installation and infrastructure	Rich Gallagher	x
16:15	Beam commissioning	Adam Bartnik	x x x
16:45	Executive session		
19:00	**DINNER - homework questions**		
Friday, February 23, 2018			
8:30	Executive session		
9:00	Homework responses	As requested	
10:00	Executive session - report writing		
12:00	Executive session - lunch in-situ for panel		
13:00	Close-out presentation	Mike Harrison	

Charge number key:

1	Main Linac Cryomodule
2	Halbach magnets and girders
3	Commissioning strategy
4	Beam tests and studies
5	International collaboration

Appendix 2 – Committee Charge

Phone 631 344-5397
bmueller@bnl.gov

BROOKHAVEN NATIONAL LABORATORY

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

Date: January 21, 2018

To: CBETA Advisory Committee

From: Berndt Mueller, Chair of the CBETA Oversight Board

Subject: Charge for the Advisory Committee meeting on February 22-23, 2018

The CBETA project is in contract with NYSERDA to build a four-pass Energy Recovery Linac. The Advisory Committee is asked to report to the CBETA Oversight Board on whether the project will be able to deliver the parameters listed in Table 1, on a schedule with the high level technical milestones shown in Table 2, and to offer advice on ways that the probability of technical success can be improved.

In particular, please evaluate and advise on:

1. **Main Linac Cryomodule:** issues and solutions identified and addressed in the testing that has already been performed with and without beam, including microphonics and the need to reliably accelerate or decelerate the beam by 36 MeV on each pass.

2. **Halbach magnets and girders:** magnet quality, arc production, integration and installation, consistent with technical milestones 7 and 8 ("Girder production run complete" and "Final assembly and pre-beam commissioning complete").

3. **Commissioning strategy:** milestones 9, 10 and 11, which outline a beam commissioning path that meets the key performance parameters. Alternative commissioning strategies under consideration could be more efficient, and could be implemented after the Fractional Arc Test in early 2018.

4. **Beam tests and studies:** results of beam tests made during "Injector CryoModule", "Main Linac Cryomodule" and other running periods. Please also evaluate and advise on low and high current beam dynamics studies and simulations designed to inform component design (eg Halbach magnets, instrumentation, impedances) and to prepare for beam commissioning (eg closed orbit correction).

5. **International collaboration:** opportunities for cost-neutral collaboration especially during the NYSERDA CBETA construction phase. Potential later phases might extend the BNL-CU collaboration, and might include additional institutions.

Please make a closeout presentation available to the CBETA Oversight Board at the end of the review, and a written report by March 15.

cc: E. Giannelis, G. Hoffstaetter, R. Michnoff, R. Patterson, S. Peggs, T. Roser, K. Smolenski, J. Thom-Levy, D. Trbojevic.

Table 1: Key Performance Parameters and ultimate design parameters.

Parameter	Unit	KPP	Design
Electron beam energy	MeV		150
Electron bunch charge	pC		123
Electron source current	mA	1	40
Bunch repetition rate (source)	MHz		325
RF frequency	MHz	1300	1300
Injector energy	MeV		6
RF operation mode			CW
Number of ERL passes		1	4
Energy apertiure of arc		2	4

Table 2: High level technical milestones.

#	NYSERDA milestone	Baseline	Actual	Forecast
	NYSERDA funding start date		31-Oct-16	
1	Engineering design documentation complete	31-Jan-17	31-Jan-17	31-Jan-17
2	Prototype girder assembled	30-Apr-17	30-Apr-17	30-Apr-17
3	Magnet production approved	30-Jun-17	23-Jun-17	30-Jun-17
4	**Beam through Main Linac Cryomodule**	**31-Aug-17**	**16-Jun-17**	**31-Aug-17**
5	First production hybrid magnet tested	31-Dec-17	21-Dec-17	31-Dec-17
6	**Fractional Arc Test: beam through MLC & girder**	**30-Apr-18**		**30-Apr-18**
7	Girder production run complete	30-Nov-18		30-Nov-18
8	Final assembly & pre-beam commissioning complete	28-Feb-19		28-Feb-19
9	Single pass beam with factor of 2 energy scan	30-Jun-19		30-Jun-19
10	Single pass beam with energy recovery	31-Oct-19		31-Oct-19
11	Four pass beam with energy recovery (low current)	31-Dec-19		31-Dec-19
12	Project complete	30-Apr-20		30-Apr-20