A PROPOSED NEW LIGHT SOURCE FACILITY FOR THE UK

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Abstract

The current status of the design of a proposed New Light Source for the UK, combining FEL and advanced conventional lasers, is presented.

INTRODUCTION

The New Light Source (NLS) project [1] was launched in April 2008 by the UK Science and Technology Facilities Council (STFC) to consider the scientific case and develop a conceptual design for a possible next generation light source based on a combination of advanced conventional laser and free-electron laser sources. Work on NLS draws on expertise from STFC Daresbury and Rutherford Laboratories, which includes the Accelerator Science and Technology Centre (ASTeC) and Central Laser Facility (CLF), Diamond Light Source, Cockcroft and John Adams Institutes, and other Universities.

The NLS project is “science driven” i.e. the first step was to define the long-term key science drivers, the second, current, step is to define the technical solution, and the third, future, step will be to request funding and decide on location.

A series of workshops in May-June 2008 defined the main scientific themes that required a new light source capability in the UK and led to the publication of a Science Case in September 2008 (see [1]), which was subsequently approved by the Physical and Life Sciences Committee and Science Board of STFC. Given the strong desire for a regular spacing of FEL pulses, for optimised data collection and efficient synchronisation to external lasers, with a repetition rate of at least 1 kHz initially, increasing later to 1 MHz, the decision was taken in November 2008 to proceed with the cw superconducting linac option for NLS – up to that point generic studies of both normal and superconducting options were being carried out in parallel [2].

In this report we summarise the current technical design of NLS, concentrating on accelerator and FEL aspects. Further details can be found in a number of companion papers [3-5].

OUTLINE DESIGN

To satisfy the objectives set out in the Science Case, the baseline specification calls for a facility that provides high brightness radiation covering a broad spectral range, from THz to a photon energy of 1 keV in the fundamental, with harmonics up to 5 keV. This will be met by three types of radiation source:

- A suite of three free-electron lasers covering the range from 50 eV to 1 keV in the fundamental, with overlapping tuning ranges as follows: FEL1: 50-300 eV, FEL2: 250-850 eV, FEL3: 430-1000 eV.
- Conventional laser sources, synchronised to the FEL sources, covering the range from 60 meV (20 μm) to 50 eV.
- Coherent THz/IR radiation from 20–500 μm generated by the electron beams after passing through each FEL, for optimal synchronisation between the FEL pulse envelope and THz/IR field.

A further requirement of the FEL sources is that they provide fully variable polarization. The current undulator design is based on the well developed APPLE-II scheme, however alternatives are also being considered. The assumed minimum operating gap is 8 mm, with ~ 6 mm internal vacuum vessel beam-stay-clear.

Calculations show that to meet the required FEL tuning ranges with realistic electron beam parameters, given the chosen undulator design, and without demanding excessive undulator lengths, requires a minimum beam energy of 2.25 GeV. A common electron energy for all three FELs, together with variable gap undulators, assures the required independent operation and easy tunability of the three FELs.

Figure 1 shows a schematic layout of the proposed facility, based on a single-pass superconducting linac [3]. An alternative design based on a recirculating linac is also under study [4], because of the potential capital and operational cost saving, and greater upgrade potential. In both cases the linac modules are based on the TESLA/XFEL designs, adapted for cw operation with an assumed maximum gradient of 20 MV/m.

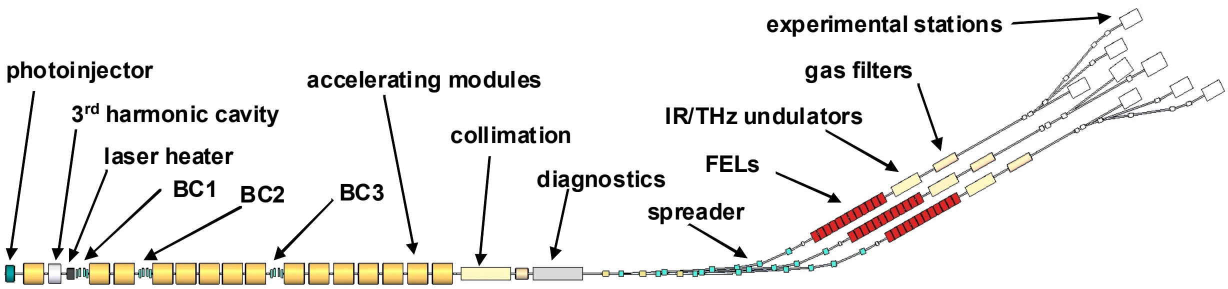

Figure 1: Schematic layout of the NLS facility.

The baseline requirement of 1 kHz operation will be met by a normal-conducting photocathode L-band gun [5], based on the successful DESY/PITZ gun4, with modified cavity geometry for lower emittance at lower field gradient, and for improved cooling. The gun is followed by an 8 cavity module in which the gradients and phases of the individual cavities are adjustable to optimise operation over a wide range of charge from 1 pC to 1 nC [5].

The linac contains 14 accelerating modules and 3 bunch compressors (BC1-3) at optimised locations (120, 410 and 1220 MeV) to optimise beam properties with a realistic 3rd harmonic cavity gradient [3]. Nominal operation is with a charge of 0.5 nC to provide a bunch with a sufficiently "flat" region (~ 250 fs) with good beam properties to allow for jitter between the electron bunch and seed laser.

Following the linac are collimation and tomography diagnostics sections, the latter incorporating a transverse deflection cavity for full slice analysis, before the beam enters the spreader region which directs successive pulses into different FEL lines by means of sets of kicker and septum magnets. This arrangement, based on the LBNL design [6], was chosen for its flexibility.

FEL SOURCES

To provide the required longitudinal coherence of the radiation, as well as the 20 fs pulse lengths, each FEL will be seeded with laser pulses obtained from High Harmonic Generation (HHG) in gases. Our current assessment, based on the rapid progress being made in this area, is that within the next ~5 years it will be possible to deliver HHG pulses with at least 400 kW peak power, with 1 kHz repetition rate, tunable over the range 50-100 eV. To obtain the required FEL output up to 1 keV, a one- or two-stage harmonic generation scheme is used, as shown schematically in Fig. 2. The number of undulator modules shown, each 2.5 m long, matches that of the simulations.

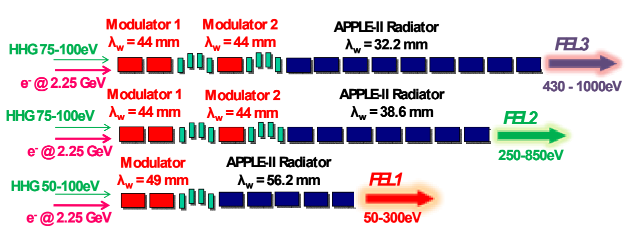

Figure 2: Schematic of the harmonic cascade FEL scheme.

The expected output power from the FELs is given in Table 1, as calculated by steady-state GENESIS calculations using electron beam parameters determined from detailed simulations of the gun and linac [3], typically 1.2-1.5 kA peak current, 0.4-0.5 μm normalised emittance and 1-2 10^{-4} rms energy spread. Pulse energies, and number of photons per pulse, in a 20 fs pulse, vary correspondingly from 250 μJ, 3 10^{13} photons/pulse at 50 eV to 30 μJ, 2 10^{11} photons/pulse at 1 keV. The output in the harmonics of the radiator fundamental are also shown, which although several orders of magnitude less intense than the fundamental are nevertheless potentially useful for experiments. Time-dependent calculations are underway to determine the temporal and spectral profiles, degree of longitudinal coherence and contrast ratio to the SASE background, and initial results are encouraging.

Eight experimental stations are currently planned. Each FEL will have one with directly focussed beam and one with a grating monochromator to improve spectral resolution and/or filter out unwanted spectral components. In addition a time-preserving grating monochromator is foreseen on FEL1, and a crystal monochromator on FEL3 for accessing the harmonics in the range 2-5 keV. The photon beam transport region has been designed to avoid the optical components being damaged by the high peak power of the FEL radiation

Table 1: Calculated FEL saturation power for the three FELs at various photon energies.

FEL#	Photon Energy	Harmonic of Radiator	Peak Power
FEL1	50 eV	1	12 GW
	100 eV	1	8.0 GW
	200 eV	1	7.2 GW
	300 eV	1	6.1 GW
FEL2	250 eV	1	4.7 GW
	500 eV	1	3.5 GW
	850 eV	1	1.7 GW
	1 keV	*3*	*60 MW*
	2 keV	*3*	*15 MW*
FEL3	500 eV	1	4.0 GW
	800 eV	1	2.1 GW
	1 keV	1	1.6 GW
	2 keV	*3*	*5.7 MW*
	3 keV	*3*	*4.2 MW*
	5 keV	*5*	*0.25 MW*

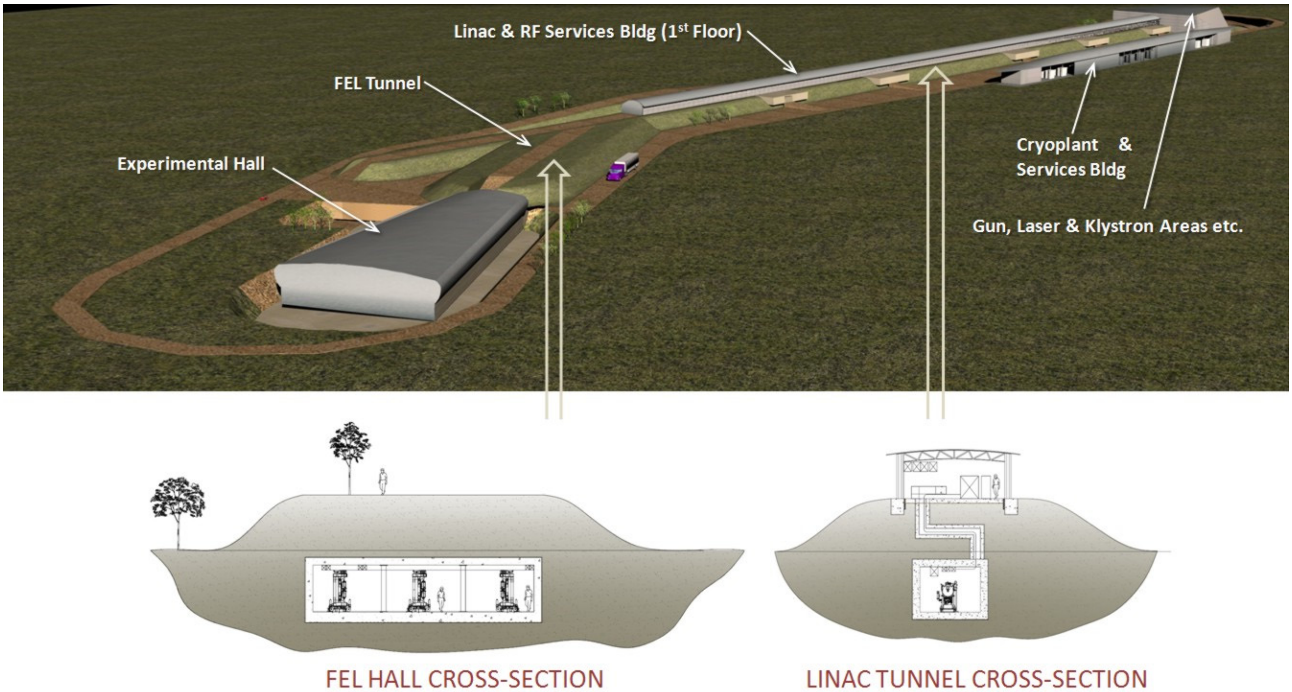

Figure 3: Architectural layout of the NLS facility.

FACILITY LAYOUT

Figure 3 presents an architect's view of the NLS facility, based on the machine and beamline layout of Fig. 1. The cross-sections show the currently preferred option for a "cut-and-fill" construction, with the linac and FEL hall below normal ground level in order to provide radiation shielding. The total building length is approximately 600 m.

UPGRADE PATHS

An important aspect of the design of NLS will be the possibility to extend its performance in future stages. The Science Case calls for the following options to be kept open for possible future development:

- Increased number of FELs and experimental stations.
- Higher photon energies, at least 1.5 keV in the fundamental, and potentially in excess of 2 keV.
- Higher repetition rates, 10-100 kHz, and eventually up to 1 MHz.
- Shorter FEL pulses, ranging from sub-fs at 1 keV to a few-fs at 100 eV.

The chosen spreader scheme and layout shown in Fig. 3 allows the possibility of extending the spreader region and adding a second FEL and experimental hall at a later date. This could be done at the same machine energy, or by incorporating an extension of the linac could provide a second set of beamlines at higher photon energy.

Higher repetition rates will require a different gun and both normal conducting VHF and superconducting L-band options are being considered. An upgrade of repetition rate will also require an upgrade of the photocathode, seed and experimental lasers.

One option being studied for achieving shorter pulses is that of the low-charge, "single-spike" operation. Calculations show that a 450 as FWHM pulse can be achieved with 200 MW peak power, corresponding to 6 10^8 photons/pulse [3]. Further studies will also be made of the various laser modulation schemes, and appropriate space left in the building design to accommodate them.

CONCLUSION

An Outline Design Report for the New Light Source is currently in preparation and due to be completed in July 2009. Subject to review and approval by STFC the aim is then to complete a Conceptual Design Report by the end of 2009 and to present the project for funding at the next call for proposals for the Large Facilities Capital Fund, which is currently expected to be in early 2010.

REFERENCES

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