Laser-hybrid Accelerator for Radiobiological Applications (LhARA)

Conceptual Design Report

The LhARA collaboration

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Management annex

A Project plan

The project plan for LhARA, see figure 1, includes:

- A programme of radiobiology;
- A programme for technology transfer, patient and public involvement, and outreach;
- A five-year R&D programme to address the technical challenges outlined in section 2;
- The schedule for constructing Stage 1 and Stage 2;
- Allocation for a project office; and
- Milestones for the Gateway process.

The radiobiology programme will commence at the start of the LhARA programme and continue through to the end. Work will be done at existing facilities prior to completing construction of LhARA Stage 1, building on existing collaborations and forging new ones. This will help develop techniques for LhARA and at the same time generate scientific output. The staff needed to deliver this are: a work package manager; one PDRA; and one PG student.

The programme of technology transfer for systems, near clinical aspects, and outreach is important to: translate the scientific output generated by LhARA into techniques and devices that can be applied in a clinical environment; involve patient and public participation right from the outset; and to communicate this to various audiences. This approach will help LhARA have a positive impact on clinical radiotherapy as early as possible. To achieve this one coordinator at 20% and one PDRA is needed.

The technical aspects of the five year R&D programme have been detailed in the various subsections on technical challenges within section 2. The staff required to complete the R&D programme include:

- **Facility design:** one work package manager; two engineers; one PDRA; and one PG student. Some effort will also cover the work needed for Stage 1 R&D, such as performance evaluation and design of the vertical bend.
- **Stage 1 R&D:** three work package managers.
  - *Gabor lens:* two PDRAs; engineering support; and three PG students.
  - *Laser:* one engineer at 30%; one PDRA; and one PG student.
  - *Investigation of space charge:* one PG student.
- **Stage 2 R&D:** two work package managers.
  - *FFA:* one magnet engineer at 50%; one RF engineer at 50%; two PDRAs; and three PG students.
  - *Injection, extraction and performance evaluation:* one PDRA.
  - *Longitudinal phase space and performance evaluation:* one PDRA; one PG student.
  - *Final beam preparation and performance evaluation:* one PG student.
- **End Stations:** work package manager, PDRA, and one PG student. The staff working on the radiobiology programme will also contribute to this at the 50% level.
- **Instrumentation:** one work package manager; two PDRAs; and three PG students.
- **Software and computing:** one work package manager; one technician; one PDRA; and one PG student.

Important milestones in the project plan are:

1. Gateway 0 – strategic assessment;
2. Gateway 1 – business justification;
3. Gateway 2 – delivery strategy;
4. Capture technology choice made;
5. Gateway 3 – investment decision;
6. Completion of Stage 1 construction; and

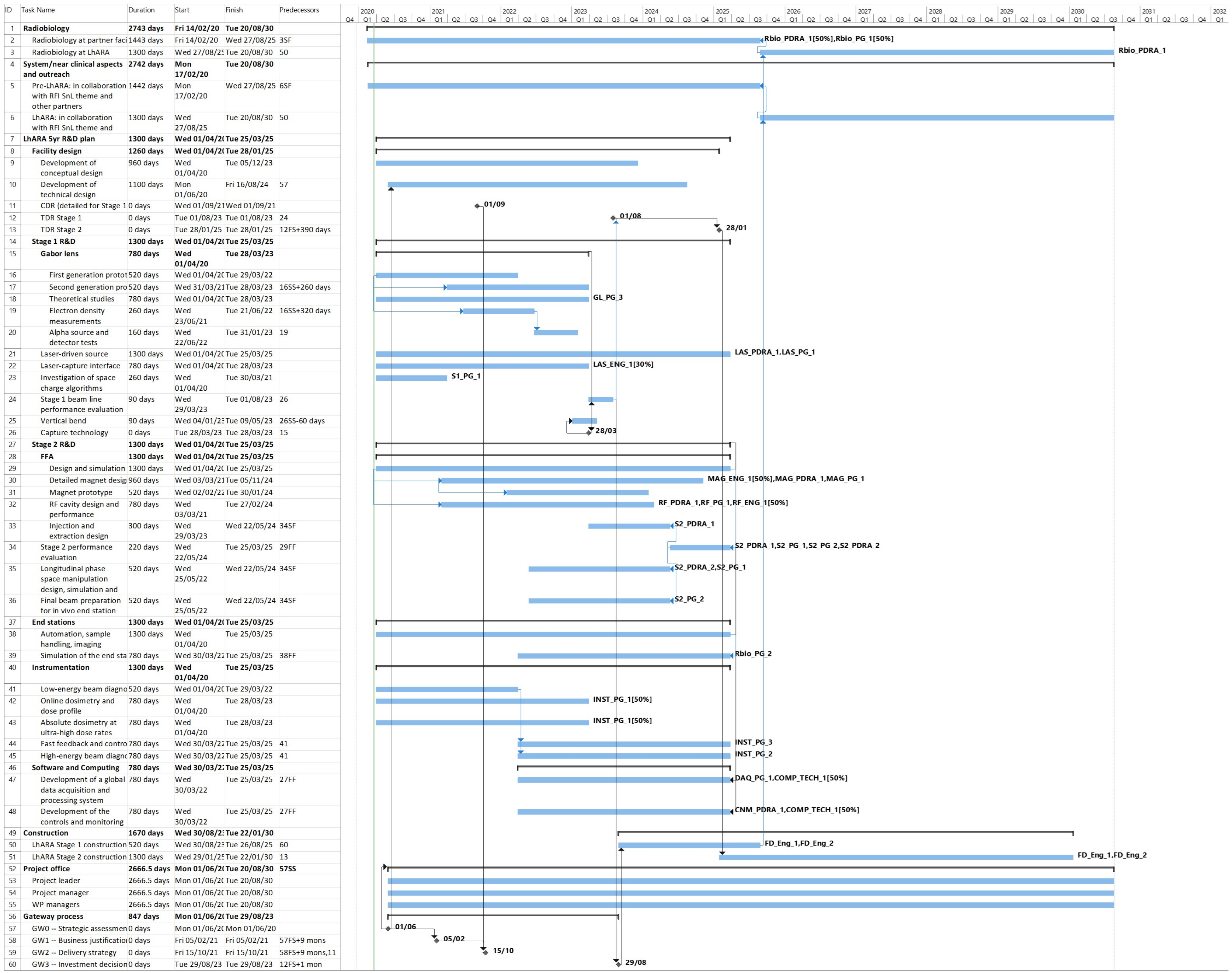

Figure 1: Gantt chart for the LhARA project.

7. Completion of Stage 2 construction.

The principal deliverables of the LhARA project are the:

1. Full Conceptual Design Report;
2. Technical Design Report for Stage 1; and
3. Technical Design Report for Stage 2.

The project office will be created when the Gateway 0 milestone is achieved. It will look after the administrative aspects of the project and will require one person to administer the project and provide support for the project leader, the project manager and the work package managers. The conceptual design report deliverable will be an input to achieve the "Gateway 2 – delivery strategy" milestone and the technical design report for Stage 1 will be an input to achieve the "Gateway 3 – investment decision" milestone. The Construction of Stage 1 will commence after the investment decision is made and construction of Stage 2 will commence after the technical design report for Stage 2 has been completed.

Capital resources for the project and the total FTEs required are detailed in Appendix B.

B Costs

The top-level breakdown of the capital costs for the LhARA project is given in table 1. The costs presented in this appendix should be regarded as first estimates that will be challenged and refined as the full CDR, and subsequently the Technical Design Reports for Stage 1 and Stage 2 are developed. The following subsections include further detail and breakdown of these costs.

Description	**Optimistic cost (£k)**	**Most likely cost (£k)**	**Pessimistic cost (£k)**
Laser	2197	2746	3295
Capture	409	545	681
Stage 1	607	759	1139
Stage 2	6924	8656	12984
End stations	799	999	1198
Integration	2612	3265	4898
R&D	400	500	600
Safety	595	850	1275
Building	4060	9160	18320
Sub total	*18603*	*27480*	*44390*
Installation and commissioning (estimate, assume 10% of capital cost)	1860	2748	4439
Total	***20463***	***30228***	***48829***
Total (incl. VAT)	**24556**	**36274**	**58595**

Table 1: Cost breakdown for the LhARA project.

Details of the staff effort required is given in section B.12. The uncertainty on the cost is based on the method used to derive the cost for each item. This is categorised as: guess, comparative, parametric, budget price from a supplier and firm quote from a supplier.

B.1 Laser

The cost for the laser system was derived using a bottom up approach and known costs, where available. A summarised cost breakdown for the laser system is given in table 2.

Description	**Optimistic cost (£k)**	**Most likely cost (£k)**	**Pessimistic cost (£k)**
Laser	1967	2458	2950
Chambers and Vacuum System	39	49	59
Laser Plasma Accelerator	82	102	123
Leakage Laser Diagnostics	21	26	32
Cameras	39	49	59
Proton Spectrometer	7	8	10
Motorised stages	20	25	30
Pointing Stabilisation System	2	3	3
Computing	5	6	7
General Electrical	16	19	23

Table 2: Cost breakdown for the laser system.

B.2 Capture

The cost breakdown for the capture system that is based on Gabor lenses is given in table 3. In the event that after studying the Gabor lens it is decided to use an alternative technology for the capture, then the cost is likely to increase.

Description	**Optimistic cost (£k)**	**Most likely cost (£k)**	**Pessimistic cost (£k)**
Gabor Lens (x5 @ £100 each)	375	500	625
Power Supply (x5 @ £3k each)	11.25	15	18.75
Cooling	22.5	30	37.5

Table 3: Cost breakdown for the capture system.

B.3 Stage 1

The cost for Stage 1 was derived using a combination of comparative, parametric and budget price methods. The magnet, power supplies and beam dump costs have been compared to equipment of approximately equal size and use at ISIS. The beampipe, frames and rails have been parametrically determined from costs of new proton beamlines under development at ISIS. The cost of diagnostics has been based on budgetary prices from suppliers for a specified quantity of installations. The breakdown of the cost for Stage 1 is given in table 4.

B.4 Stage 2

The cost for Stage 2 was derived using a combination of comparative, parametric, guess and budget price methods. The quadrupole and dipole magnets, power supplies and beam dump costs have been compared to

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Quadrupole Magnets (x12 @ £10k each)	96	120	180
Dipole Magnets (x9 @ £10k each)	72	90	135
Power Supplies (x21 @ £3k each)	50	63	95
Beam Dump	24	30	45
Beampipe (12m @ £3k/m)	29	36	54
Frames (12m @ £5k/m)	48	60	90
Rails (12m @ £5k/m	48	60	90
Diagnostics (12m @ £25k/m)	240	300	450

Table 4: Cost breakdown for Stage 1.

equipment of approximately equal size and use at ISIS. The beampipe, frames and rails have been parametrically determined from costs of new proton beamlines under development at ISIS. The FFA magnets and RF cavities have been estimated via guesses, while also comparing to the most closely comparable equipment in use at ISIS. The cost of diagnostics has been based on budgetary prices from suppliers for a specified quantity of installations. The breakdown of the cost for Stage 2 is given in table 5.

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Quadrupole Magnets (x20 @ £10k each)	192	240	360
Dipole Magnets (x10 @ £10k each)	80	100	150
Power Supplies (x32 @ £3k each)	77	96	144
Beam Dump (x2 @ £15k each)	48	60	90
FFA Magnets (x10 @ £250k each)	2000	2500	3750
FFA magnet power supply (x10 @ £75k each)	600	750	1125
RF Cavities (x4 @ £300k each)	960	1200	1800
RF Power supply/drive system (x4 at £400k each)	1280	1600	2400
Kicker Magnets (x2 @ £200k each)	320	400	600
Septum Magnets (x2 @ £200k each)	320	400	600
Kicker & Septum power supplies (x4 @ £60k each)	192	240	360
Bunching Cavities (x4 @ £30k each)	96	120	180
Beam pipe (25m @ £3k/m)	60	75	113
Frames (25m @ £5k/m)	100	125	188
Rails (25m @ £5k/m	100	125	188
Diagnostics (25m @ £25k/m)	500	625	938

Table 5: Cost breakdown for Stage 2.

B.5 End stations

The cost breakdown for the end stations is the cost to equip the end stations, see table 6. These costs have been based on budget prices from suppliers. The costs for other equipment such as consumables is not included and the cost for the end station automation is included in the costs for the R&D programme.

Description	**Optimistic cost (£k)**	**Most likely cost (£k)**	**Pessimistic cost (£k)**
Refrigerated centrifuge (x2) - Eppendorf 5804R	9.6	12	14.4
Refrigerated ultracentrifuge - Beckman Coulter Optima MAX-XP	40	50	60
Hypoxia chamber - Baker InvivO2/Don Whitley	32	40	48
Ice Flaker machine - Scotsman AF80	2	2.5	3
CellRad x-ray irradiator - Faxitron	56	70	84
Class II cell culture cabinet (x4) - Esco Airstream	22.4	28	33.6
Digital microscope - Invitrogen EVOS M5000	16	20	24
Light microscopes (x3) - Nikon Eclipse TS100	7.2	9	10.8
CO2 cell incubator (x2) - Panasonic	11.2	14	16.8
Fridges/-20°C Freezers (4 each)	1.6	2	2.4
-80°C Freezers (x2) - Panasonic	16	20	24
MilliQ water - Avidity 60L	4.8	6	7.2
Colony counter - Oxford Optronix GelCount	20	25	30
Fluorescence microscope/Live cell imaging	80	100	120
Robotic workstation (research laboratory) – Tecan/Beckman	160	200	240
End station cabinet (hypoxia enabled) - BakerRuskinn/Don Whitley	160	200	240
Robotics within end station cabinets (x2)	160	200	240

Table 6: Cost breakdown for the end stations.

B.6 Integration

The costs for the integration were estimated using comparative and parametric methods based on new proton beamline projects currently in development at ISIS. The costs for integration are given in table 7.

B.7 R&D

The costs for R&D were derived using a combination of comparative and guess methods. Material costs for computing includes cost for CPU nodes as well as infrastructure related costs such as networking (including cable pulling), etc. The costs for the R&D are given in table 8.

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Vacuum systems (35m @ £34k/m)	952	1190	1785
Electrical services (35m @ £25k/m)	700	875	1312.5
Water services (35m @ £20k/m)	560	700	1050
Control system	400	500	750

Table 7: Cost breakdown for integration.

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Gabor lens prototype material	200	250	300
Computing hardware	160	200	240
Instrumentation prototype hardware	40	50	60

Table 8: Cost breakdown for the R&D programme.

B.8 Safety

The costs for the necessary safety systems have been based on parametric and comparative methods using examples from safety systems at ISIS. The costs for the safety systems are given in table 9.

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Shielding	385	550	825
Access Controls and PPS	210	300	450

Table 9: Cost breakdown for the safety system.

B.9 Building

The building cost was derived from the actual cost for a building of comparable size to that needed for LhARA. The optimistic cost for the building structure is listed as zero in the event that an existing building can be re-purposed for use with LhARA. The supporting works, such as mechanical and services, would still be required for this existing building. The costs for the building requirements are given in table 10.

B.10 Installation and commissioning

The estimated cost of installation and commissioning is based on the experience gained at the Rutherford Appleton Laboratory in the implementation of projects of a similar scale. 10% of the total capital budget has been assumed as the cost of installation in the LhARA hall, system commissioning, and overall integration (see table 1). Installation and commissioning costs for specific equipment has been assumed to be included in the cost of that item.

Description	Optimistic cost (£k)	Most likely cost (£k)	Pessimistic cost (£k)
Building structure	0	3360	6720
Mechanical and electrical	980	1400	2800
Externals and services	1750	2500	5000
Enabling and preparation works	980	1400	2800
Cranes	350	500	1000

Table 10: Cost breakdown for building.

B.11 Project

There are no specific capital costs envisaged to manage the project. There is one person included in the project plan to administer the project and provide support for the project leader, project manager and work package managers and this is included in the staff requirements detailed in section B.12.

B.12 Staff

The required staff effort is given in table 11 in terms of FTEs needed for the different roles specified in the project plan, see section A. Thus this only includes staff where specific positions have been identified. It is expected that more effort will be needed, especially for construction, though to determine this with any confidence requires a more detailed analysis of the project plan. A rough guide for the number of FTEs needed for this can be taken from past experience and is expected, in terms of cost, to be of the same order as the capital cost.

Type of position	Number of FTEs
Academic	10.7
Administrative	10.3
Engineering	27.9
Post-doctoral Research associate	61.2
Post-graduate student	50.7
Technical/support	5.1

Table 11: Breakdown of the staff effort estimated as required for the execution of the LhARA project.

It should be noted that the academic FTEs are for work package managers, which have been included in the project plan at 20%. Other academic effort, for example for supervising students and providing specific technical expertise, is not included but will be required.

C Version history

30$^{\text{th}}$ April 2020; "Final":

Final version of LhARA pre-CDR released following review by international expert panel [1].

4$^{\text{th}}$ June 2020; "Final—revision 1":

Pre-CDR documented updated to bring details of the post acceleration into line with the paper submitted for publication [2]. Instantaneous and average dose rate calculations updated as well as details of the post-acceleration.

10^{th} July 2020; "Final—revision 2":
Management Annex updated to include installation and commissioning costs.

References

[1] "Pre-publication review of the LhARA pre-CDR." https://ccap.hep.ph.ic.ac.uk/trac/wiki/Research/DesignStudy/PreCDR/Review, April, 2020. Accessed: 2020-04-30.

[2] **LhARA** Collaboration, G. Aymar *et al.*, "The Laser-hybrid Accelerator for Radiobiological Applications," 2006.00493.