The Laser-hybrid Accelerator for Radiobiological Applications

Scope of work to be carried out under the ITRF Preliminary Activity

The LhARA collaboration

1 Introduction

The LhARA collaboration's [1, 2] proposal for an initial five-year R&D programme designed to deliver the essential risk-mitigating R&D programme and to establish the technical design for the LhARA facility is presented in [3]. The proposal was aligned to the timescale defined in the proposal to the UKRI Infrastructure Fund for the establishment of the Ion Therapy Research Facility (ITRF) [4]. LhARA formed the basis for the ITRF proposal.

The ITRF proposal was for resources to support a two-year "Preliminary Activity". The principal deliverable of the two-year Preliminary Activity is a complete Conceptual Design Report for the facility. The ITRF proposal identified a subsequent, three-year, "Preconstruction Phase". Resources for the Preconstruction Phase will be sought during the Preliminary Activity. The first two years of the LhARA proposal [3] is designed to coincide with the Preliminary Activity defined in the ITRF proposal, while years three to five are designed to coincide with the Preconstruction Phase.

In June 2022 UKRI announced £2M over two years for the ITRF as one of the projects supported by the Infrastructure Fund in 2022 [5]. The ITRF project will be carried out through four Work Packages [6]:

0. Management and CDR;
1. LhARA;
2. ITRF Facilities and Costing; and
3. Conventional Technology.

It is anticipated that the ITRF Preliminary Activity funding line will provide a total of £1.81M to support the development of LhARA to serve the ITRF [6]. This total is broken down as follows:

- ITRF Work Package 1: £1.49M to support LhARA technical-risk mitigation and preparation of the CDR; and
- ITRF Work Package 2: £0.32M to support the evaluation of the conventional technical facilities and to produce a cost estimate of the facility for inclusion in the CDR.

The STFC Particle Physics Department (PPD) has provided £28k to support the optimisation of the Stage 1 and Stage 2 beam lines. Resources will be made available to allow the ITRF project, and therefore the LhARA project, to start on the 1st October 2022.

This annex to the LhARA proposal [3] documents the programme that the LhARA collaboration will carry out under the ITRF funding line and the support provided by PPD. This document defines the scope of work and presents the cost and schedule. The scientific justification, risk analysis, organisational and managerial structures, and the reporting arrangements remain as described in [3] and are not repeated here. The collaboration is actively seeking the resources necessary to carry out the full two-year scope described in [3].

2 Work package details

2.1 Work Package 1: Project management

Objectives

The objectives of Work Package 1 are to:

1. Organise:
   - Bi-weekly Work Package Managers (WPM) progress meetings;
   - Monthly WPM reporting in preparation for the monthly report to ITRF Management. This will include:
     - Review of progress by work package;
     - Risk register review and update;
     - Spend update.
   - LhARA Collaboration meetings which will be held 6 monthly in advance of LhARA deliverables to ITRF;
2. Support the organisation of:
   - Peer-group and stakeholder consultation activities through which the specification of the facility will be defined. The organisation of these consultations are principally the responsibility of *Work Package 5; Novel end-station development*. Work Package 1 support for this activity is justified by its importance to the development of the LhARA programme;
   - LhARA outreach and PPI activities including:
     - User community engagement;
     - Patient and Public Involvement (PPI);
     - Development of the LhARA website;
     - Champion the development of impact from the LhARA project and the wider LhARA initiative.
3. Report to the ITRF management.

Deliverables

The following are deliverables to the ITRF project under the ITRF funding line. Deliverables are labelled "**D1.n**". Each deliverable corresponds to a milestone ("**M1.n**").

D1.1 (month 6): Early review of progress towards the CDR (**M1.1**);
D1.2 (month 12): Interim review of progress towards the CDR (**M1.2**);
D1.3 (month 18): Early draft of the LhARA CDR and LhARA contributions to the ITRF CDR (**M1.3**); and
D1.4 (month 24): Complete LhARA CDR and LhARA contributions to the ITRF CDR (**M1.n**).

Resources

The resources to support Work Package 1: Project Management are summarised in table 1.

Gantt chart and principal milestones

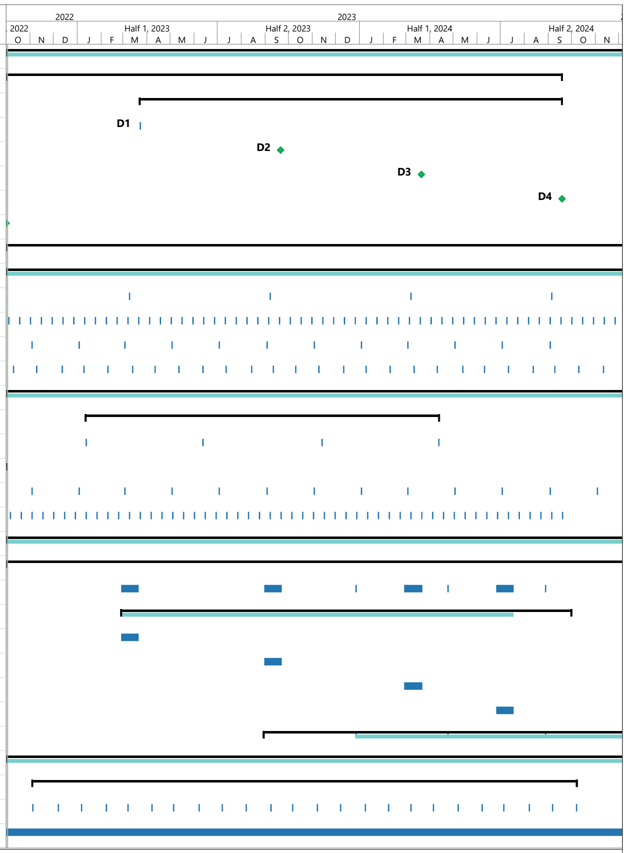
The programme of work for Workpackage 1 is shown in table 2.

Table 1: Resources required to execute Work Package 1.

LhARA Work Package 1: Project Management	J. Parsons, C. Whyte					04/10/2022
Staff	**Year 1**		**Year 2**		**Total**	
	Fraction	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
Project office support						
Strathclyde Physics						
Strathclyde-Phys-Stf-1	0.5	80.00	0.5	80.00	1	160.00
Cost of risk mitigation, staff:		0.00		0.00		0.00
Staff total:	0.5	**80.00**	**0.5**	**80.00**	**1**	**160.00**
Non-staff		**£k**		**£k**		**£k**
Project office support						
Collaboration meetings - 3 per year		2.50		2.50		5.00
Equipment total:		**2.50**		**2.50**		**5.00**
Inflation (not yet implemented):		0.00		0.00		0.00
Consumables		0.00		0.00		0.00
Travel		4.00		4.00		8.00
Cost of risk mitigation, equipment (not yet implemented):		0.00		0.00		0.00
Working margin:		0.00		0.00		0.00
Contingency, equipment:		0.00		0.00		0.00
Contingency, CG staff:		0.00		0.00		0.00
Contingency, all staff:		0.00		0.00		0.00
Total:		**86.50**		**86.50**		**173.00**

Table 2: Gantt chart showing the programme of work for Work Package 1.

ID	Task Name	Work Package	Start
2	**WP1 Project Management**	**WP1**	**Sat 01/10/22**
3	**Project Deliverables**	**WP1**	**Sat 01/10/22**
4	**Year 1&2**	**WP1**	**Thu 23/03/23**
5	**Early Progress Review CDR**	**WP1**	**Thu 23/03/23**
6	**Interim Progress Review CDR**	**WP1**	**Thu 21/09/23**
7	**Pre-CDR Review**	**WP1**	**Thu 21/03/24**
8	**CDR**	**WP1**	**Thu 19/09/24**
9	**Year 3-5**	**WP1**	**Sat 01/10/22**
16	**Tasks**	**WP1**	**Sat 01/10/22**
17	Task1 : LhARA Project Management - monitoring of schedule, cost and risk.	**WP1**	**Sat 01/10/22**
18	**Internal Reporting / input to LhARA progress reports**	**WP1**	**Fri 14/10/22**
47	**LhARA Project Group meeting (WPM)**	**WP1**	**Tue 04/10/22**
168	**Insitute board meetings**	**WP1**	**Sat 01/10/22**
182	**Project Office admin focused meeting**	**WP1**	**Mon 10/10/22**
243	Task 2: Outreach and engagement	**WP1**	**Sat 01/10/22**
244	**Peer group and stakeholder consultation**	**WP1**	**Thu 12/01/23**
245	**Stakeholder an Peer group consultation**	**WP1**	**Thu 12/01/23**
250	**Outreach**	**WP1**	**Sat 01/10/22**
257	**Insitute board meetings**	**WP1**	**Sat 01/10/22**
290	**Executive Board Meeting**	**WP1**	**Thu 06/10/22**
343	Task 3: Reporting to ITRF	**WP1**	**Sat 01/10/22**
344	**Reporting**	**WP1**	**Sat 01/10/22**
345	**Preparation of deliverables**	**WP1**	**Mon 27/02/23**
346	**Year 1&2**	**WP1**	**Mon 27/02/23**
347	Preparation for D1	WP1	Mon 27/02/23
348	Preparation for D2	WP1	Thu 31/08/23
349	Preparation for D3	WP1	Wed 28/02/24
350	Preparation for D4	WP1	Wed 26/06/24
351	**Year 3-5**	**WP1**	**Wed 30/08/23**
362	**STFC Project Risk Committee**	**WP1**	**Sat 01/10/22**
363	**Year 1&2**	WP1	Fri 04/11/22
364	**LhARA input to ITRF PRC**	**WP1**	**Fri 04/11/22**
389	Year 3-5	WP1	Sat 01/10/22



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2.2 Work package 2: Laser-driven proton and ion source

Objectives

The objectives for *Work Package 2: Laser-driven proton and ion source* are to begin the design of a stable laser-driven high-flux proton and ion source capable operating at 10 Hz. Under the ITRF funding line, we will make full or partial progress on 4 of the objectives (**O2.n**) described in the full LhARA proposal:

O2.1: Complete set of simulations to set the baseline of the proton and ion production rates and spectra for LhARA;

O2.2: Development of specification of the package of diagnostics required for LhARA commissioning and operation;

O2.3: Execution of a set of experiments on SCAPA to benchmark the baseline simulation

O2.4: Complete initial studies of the advanced targetry system needed for LhARA, the debris that will be produced, and schemes to stabilise the target and particle spectra.

Tasks

To realise the objectives set out above, the following condensed set of tasks will be carried out under the ITRF funding line:

O2.1: Baseline simulations:

- Convergence testing and bench-marking
- Hydrodynamic modelling of laser contrast
- 2D PIC modelling of TNSA for proton acceleration on SCAPA
- 3D "full scale" simulations for proton acceleration on SCAPA
- 2D PIC modelling of TNSA for heavy ion acceleration on SCAPA
- 3D 'full scale' simulations for heavy ion acceleration on SCAPA

O2.2: Diagnostic package:

- Concept design for diagnostic platform
- Testing preliminary ion diagnostics

O2.3: Baseline SCAPA experiments:

- SCAPA ion source commissioning experiment design, beam-time and analysis
- Simulation bench-marking and iteration
- Parametric optimisation experiment design, beam-time and analysis

O2.4: Advanced targetry, debris and stabilisation studies

- Source characterisation experiment at ICL design, beam-time and analysis
- Debris and contaminant removal experiment at ICL design, beamtime and analysis

Resources

The resources to support *Work Package 2: Laser-driven proton and ion source* are summarised in table 3.

Table 3: Resources required to execute Work Package 2.

LhARA WP2: Laser-driven proton and ion source	E. Boella, N. Dover, R. Gray					04/10/2022
	Year 1		Year 2		Total	
Staff	**Fraction**	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
All						
Strathclyde Physics						
Strathclyde-Phys-PDRA-1	0.5	61.50	0.5	61.50	1	123.00
Strathclyde-Phys-Stf-2	0.1	13.50	0.1	13.50	0.2	27.00
Imperial Physics						
IC-Phys-Stf-1	0.43	73.17	0.5	85.48	0.93	158.66
Lancaster Physics						
Lanc-Phys-Stf-1	0.05	7.50	0.05	7.50	0.1	15.00
Lanc-Phys-PDRA-1	0.5	60.00	0.5	60.00	1	120.00
Queen's Physics						
Qns-Phys-Stf-1	0.05	6.50	0.05	6.50	0.1	13.00
Cost of risk mitigation, staff (not yet implemented):						
Staff total:	1.628	**222.17**	**1.7**	**234.48**	**3.328**	**456.66**
Non-staff		**£k**		**£k**		**£k**
All						
Equipment total:						
Inflation:						
SCAPA Access		17.00		57.00		74.00
Imperial Access		23.00		23.00		46.00
Costs for domestic travel to beamtime at Strathclyde/Imperial		8.00		16.00		24.00
Consumables		17.50		17.50		35.00
Travel		2.00		4.00		6.00
Cost of risk mitigation, equipment (not yet implemented):						
Working margin:						
Contingency, equipment:						
Contingency, CG staff:						
Contingency, all staff:						
Total:		**289.67**		**351.98**		**641.66**

Gantt chart and principal milestones

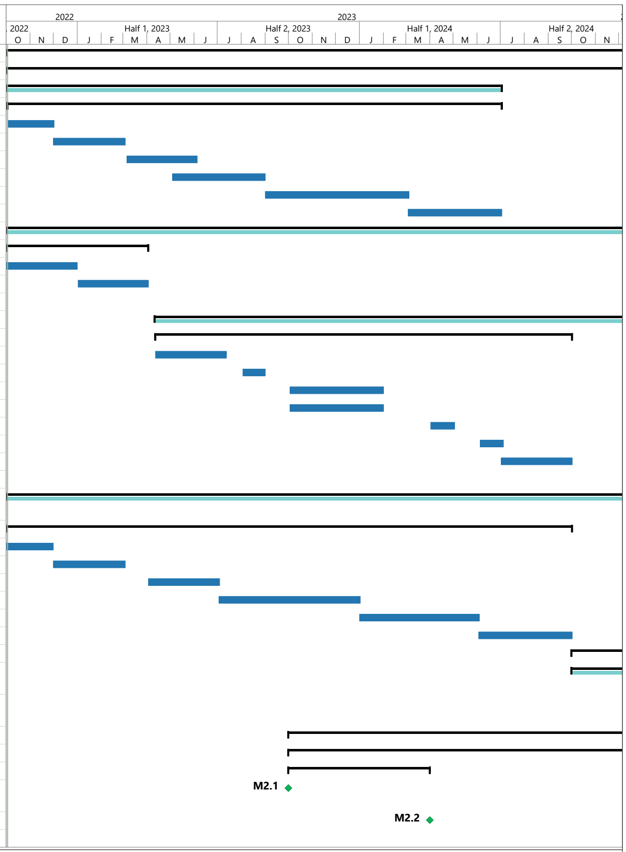
The following are the milestones (**M2.n**) for Work Package 2 under the ITRF funding line.

- **M2.1** (month 12): Report on prediction of optimised proton source parameters for 100+ TW laser systems based on hydrodynamic and kinetic simulations
- **M2.2** (month 18): Report on first SCAPA ion source simulations and experiment completed (Month 18)

The programme of work for Workpackage 2 is shown in table 4.

Table 4: Gantt chart showing the programme of work for Work Package 2.

ID	Task Name	Work Package	Start
390	**WP2 Source**	**WP2**	**Sat 01/10/22**
391	**Tasks - Objectives**	**WP2**	**Sat 01/10/22**
392	**O 1 - Baseline simulations - Lancaster**	**WP2**	**Sat 01/10/22**
393	**PA1, yrs 1&2**	**WP2**	**Mon 03/10/22**
394	Convergence Testing and Benchmarking	WP2	Mon 03/10/22
395	Hydrodynamic modelling of laser contrast	WP2	Thu 01/12/22
396	2D PIC modelling of TNSA for proton acceleration on SCAPA	WP2	Mon 06/03/23
397	3D 'full scale' simulations for proton acceleration on SCAPA	WP2	Thu 04/05/23
398	2D PIC modelling of TNSA for heavy ion acceleration on SCAPA	WP2	Fri 01/09/23
399	3D 'full scale' simulations for heavy ion acceleration on SCAPA	WP2	Mon 04/03/24
400	**O2 - Diagnostic package (Strath - ICL)**	**WP2**	**Sat 01/10/22**
401	**PA1 yrs1&2**	**WP2**	**Sat 01/10/22**
402	Concept design for diagnostic platform	WP2	Sat 01/10/22
403	Testing preliminary ion diagnostics	WP2	Mon 02/01/23
404	**PA2 yrs3-5**	**WP2**	**Wed 02/04/25**
409	**O3 - Baseline SCAPA experiments (Strath)**	**WP2**	**Tue 11/04/23**
410	**PA1 yrs1&2**	**WP2**	**Wed 12/04/23**
411	Experiment planning, Design and Preparation	WP2	Wed 12/04/23
412	SCAPA ion source commissioning experiment	WP2	Thu 03/08/23
413	Data Processing and Analysis	WP2	Tue 03/10/23
414	Simulation Benchmarking and Iteration	WP2	Tue 03/10/23
415	Experiment planning, Design and Preparation B	WP2	Tue 02/04/24
416	SCAPA experiment on parametric optimisation of source	WP2	Wed 05/06/24
417	Data Processing and Analysis	WP2	Tue 02/07/24
418	**PA2 yrs3-5**	**WP2**	**Tue 31/12/24**
422	**O4 - Advanced targetry, debris and stablisation studies (ICL/ Lancaster)**	**WP2**	**Sat 01/10/22**
423	**PA1 yrs1&2**	**WP2**	**Sat 01/10/22**
424	Experiment Planning, Design and Preparation	WP2	Sat 01/10/22
425	Initial Baseline Experiment at IC for source characterisation and stability	WP2	Thu 01/12/22
426	Data Processing and Analysis	WP2	Mon 03/04/23
427	Experiment Planning, Design and Preparation	WP2	Mon 03/07/23
428	Base line experiment for debris and contaminant removal studies	WP2	Mon 01/01/24
429	Data Processing and Analysis	WP2	Mon 03/06/24
430	**PA2 yrs3-5**	**WP2**	**Tue 01/10/24**
437	**O5 - Complete source design, integrate with capture (Strath, IC + WP3)**	**WP2**	**Tue 01/10/24**
445	**O6 - High Repetition Rate Operations at Full Specification (Strath, IC, Lanc, WP3)**	**WP2**	**Thu 01/10/26**
455	**Reporting / Milestones**	**WP2**	**Sun 01/10/23**
456	**Milestones**	**WP2**	**Sun 01/10/23**
457	**PA1 yrs1&2**	**WP2**	**Sun 01/10/23**
458	**M2.1: Prediction of optimised proton source parameters for 100+ TW laser systems based on hydrodynamic and kinetic simulations**	WP2	Sun 01/10/23
459	**M2.2: First SCAPA ion source simulations and experiment completed.**	WP2	Mon 01/04/24
460	**PA2 yrs3-5**	**WP2**	**Tue 01/04/25**



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2.3 Work package 3: Proton and ion capture

Objectives

The objectives (**O3.n**) of *Work Package 3: Proton and ion capture* for the 24-month Preliminary Activity are:

O3.1: Use existing apparatus at Swansea University to make measurements of electron-plasma dynamics that will be used to evaluate and bench-mark numerical simulations. The measurement, simulation and analysis will be used to gain insights and understanding as part of the Gabor-lens risk-management programme; and

O3.2: Develop a detailed design of the next generation Gabor-lens prototype based upon state-of-the art plasma techniques and including the guidance gained from the associated simulations.

Tasks

The principal task that will be carried out to meet the objectives set out above is the detailed design of a stand alone Gabor lens test bench to be constructed during the Preconstruction Phase. The test bench will be capable of operating at 2 kV and of being interfaced with an appropriate ion source. Potential suppliers will be identified for all necessary components.

Intermediate milestones by which progress can be monitored will take the form of progress reports on progress towards the objectives set out above.

Resources

The ITRF resources requested to support Work Package 3: Proton and ion capture are summarised in table 5.

Table 5: Resources required to execute Work Package 3.

LhARA WP3 Proton and ion capture	C. Baker, W. Bertsche					04/10/2022
	Year 1		Year 2		Total	
Staff	**Fraction**	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
Preliminary activity						
Manchester Physics						
Man-Phys-Stf-1	0.1	20.75	0.1	20.75	0.2	41.50
Swansea Physics						
Swns-Phys-PDRA-1	1	107.70	1	107.70	2	215.40
Swns-Phys-Stf-1	0.1	18.89	0.1	18.89	0.2	37.78
Cost of risk mitigation, staff (not yet implemented):						
Staff total:	1.2	**147.34**	**1.2**	**147.34**	**2.4**	**294.68**
Non-staff		**£k**		**£k**		**£k**
All						
Preliminary activity						
Vacuum Generation		23.00				23.00
Vacuum Hardware		1.00				1.00
Trap/Expt. Hardware		9.50				9.50
Diagnostics		10.00				10.00
Control		5.00		3.00		8.00
Misc.		1.00		1.00		2.00
Equipment total:		**49.50**		**4.00**		**53.50**
Inflation:						
PPI, engagement, outreach		2.00		2.00		4.00
Consumables		14.50		17.00		31.50
Travel		10.00		15.00		25.00
Cost of risk mitigation, equipment (not yet implemented):						
Working margin:						
Contingency, equipment:						
Contingency, CG staff:						
Contingency, all staff:						
Total:		**223.34**		**185.34**		**408.68**

Gantt chart and principal milestones

The milestones (**M3.n**) defined to monitor progress towards the principal deliverable are:

M3.1 (month 6): Report on the modification of the existing apparatus to accommodate the study of electron-plasma dynamics and to validate numerical codes;

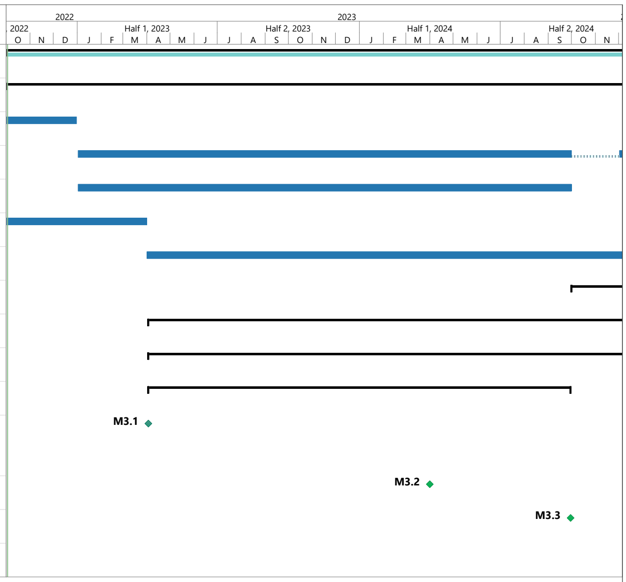
M3.2 (month 12): Report describing the performance of the modified apparatus in initial electron-plasma experiments. The report will record the observations and compare them with the results of numerical simulation; and

M3.3 (month 18): Report on the study of electron plasmas documenting progress towards understanding their behaviours under the conditions expected in the next generation Gabor-lens prototype.

The programme of work for Workpackage 3 is shown in table 6.

Table 6: Gantt chart showing the programme of work for Work Package 3.

ID	Task Name	Work Package	Start
464	**WP3 Proton and ion capture**	**WP3**	**Sat 01/10/22**
465	**PA1 yrs 1&2**	**WP3**	**Sat 01/10/22**
466	Order & install hardware for exisiting apparatus	WP3	Sat 01/10/22
467	Investigate low voltage plasma with existing apparatus	WP3	Mon 02/01/23
468	Fully design, identify suppliers, and cost testbench	WP3	Mon 02/01/23
469	PIC modelling validation	WP3	Sat 01/10/22
470	PIC modelling of exisiting testbench hardware	WP3	Sat 01/04/23
471	**PA2 yrs3-5**	**WP3**	**Tue 01/10/24**
478	**Reporting/Milestones**	**WP3**	**Mon 03/04/23**
479	**Milestones**	**WP3**	**Mon 03/04/23**
480	**PA1 yrs1&2**	**WP3**	**Mon 03/04/23**
481	**M3.1 Validate plasma simulations with existing Swansea experimental set-up**	WP3	Mon 03/04/23
482	**M3.2 Progress report of large diameter plasma experiments and simula**	WP3	Mon 01/04/24
483	**M3.3 Next generation plasma lens testbench design**	WP3	Mon 30/09/24
484	**PA2 yrs 3-5**	**WP3**	**Tue 30/09/25**



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2.4 Work package 4: Ion-acoustic dose mapping

Objectives

The *Work Package 4; Ion-acoustic dose mapping* objectives (**O4.n** for the 24-month Preliminary Activity are:

O4.1: The development of the Geant4 simulation of the forward model;

O4.2: The development of the k-wave forward acoustic model; and

O4.3: The design an appropriate experiment to prove the principle of ion-acoustic dose-mapping for LhARA to be carried out in the Preconstruction Phase.

Tasks

The principal task is the detailed design of the proof-of-principle experiment to be executed during the Preconstruction Phase. Potential suppliers will be identified for all necessary components.

Intermediate deliverables will take the form of progress reports on progress towards the objectives set out above.

Resources

The resources to support Work Package 4 are summarised in table 7.

Table 7: Resources required to execute Work Package 4.

LhARA WP4: Ion acoustic dose-profile measrement	J. Bamber, E. Harris, J. Matheson					04/10/2022
	Year 1		Year 2		Total	
Staff	**Fraction**	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
All						
ICR, Radiotherapy and Imaging						
ICR Staff 1	0.05	11.00	0.05	11.00	0.1	22.00
ICR Staff 2	0.05	9.95	0.05	9.95	0.1	19.90
UCL, Biomedical Engineering						
UCL Staff 1	0.05	8.75	0.05	8.75	0.1	17.50
STFC-PPD						
STFC-PPD Staff 1 (Matheson)	0.04	6.00	0.04	6.00	0.08	12.00
Cost of risk mitigation, staff (not yet implemented):		0.00		0.00		0.00
Staff total:	0.19	**35.70**	**0.19**	**35.70**	**0.38**	**71.40**
Non-staff		**£k**		**£k**		**£k**
All						
Hardware for smartphantom assembly		5.00		0.00		5.00
Equipment total:		**5.00**		**0.00**		**5.00**
Inflation:		0.00		0.00		0.00
PPI, engagement and Outreach		0.00		2.00		2.00
Consumables		5.00		5.00		10.00
Travel		5.00		5.00		10.00
Cost of risk mitigation, equipment (not yet implemented):		0.00		0.00		0.00
Working margin:		0.00		0.00		0.00
Contingency, equipment:		0.00		0.00		0.00
Contingency, CG staff:		0.00		0.00		0.00
Contingency, all staff:		0.00		0.00		0.00
Total:		**50.70**		**47.70**		**98.40**

Gantt chart and principal milestones

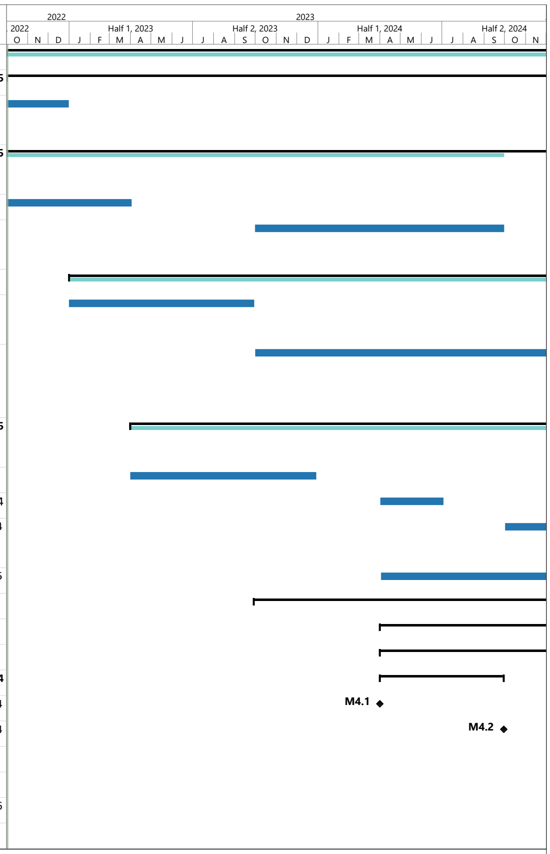
The milestones (**M4.n**) identified to monitor progress towards the principal deliverable are:

- **M4.1** (month 6): Report on the forward simulation of the energy deposited by the beam impinging on an instrumented water phantom (the SmartPhantom) and the deposition of energy resolved in four dimensions (three space and one time). The simulation will be performed using Geant4;
- **M4.2** (month 10): Report on the results of the forward simulation and its use to optimise the performance of the SmartPhantom and to provide the power-density spectrum required as input to the acoustic model.
- **M4.3** (month 12): Report on the development of a k-wave-based simulation of the acoustic wave generated by by the energy deposited by the beam. The simulation will be used to quantify the magnitude of the pressure wave and to estimate the expected acoustic-sensor response;
- **M4.4** (month 16): Report on the exploitation of the forward acoustic model to optimise the specifications for the acoustic-sensor array.
- **M4.5** (month 18): Report on the design and specification of the experiment required to prove the principle of the ion-acoustic dose-mapping technique for LhARA.

The programme of work for Workpackage 4 is shown in table 8.

Table 8: Gantt chart showing the programme of work for Work Package 4.

ID	Task Name	Work Package	Start	Finish
489	**WP4 Ion-acoustic**	**WP4**	**Sat 01/10/22**	**Thu 30/09/27**
490	**PA1 yrs 1&2**	**WP4**	**Sat 01/10/22**	**Mon 29/09/25**
491	1. Review - Current state of the art: ionacoustics / modelling of ionacoustics / proton dosimetry	WP4	Sat 01/10/22	Fri 30/12/22
492	**2. Development of GEANT 4 Monte Carlo part of the forward model**	**WP4**	**Sat 01/10/22**	**Mon 29/09/25**
493	2.1.Simulation of current beam line and smart phantom	WP4	Sat 01/10/22	Sat 01/04/23
494	2.2.Updated simulation of LhARA and smart phantom, as the specifications are developed in WPs 2,3,5 and 6.	WP4	Sun 01/10/23	Sun 29/09/24
495	**3. Development of k-Wave forward acoustic model**	**WP4**	**Sun 01/01/23**	**Fri 27/12/24**
496	3.1.Simulation of ionacoustic source, propagation and sensing, and design of array configuration for validation experiments	WP4	Sun 01/01/23	Thu 28/09/23
497	3.2.Updated simulation of ionacoustic source, and development of sensor array specification as Lhara specifications are developed	WP4	Sun 01/10/23	Fri 27/12/24
498	**4. Implementation, simulation evaluation and development of inverse dose-map reconstruction software**	**WP4**	**Sat 01/04/23**	**Wed 02/07/25**
499	4.1. Direct ionacoustic reconstruction with handling of sensor array c	WP4	Sat 01/04/23	Thu 28/12/23
500	4.2. Iterative reconstruction methods with model-based priors from :	WP4	Tue 02/04/24	Tue 02/07/24
501	4.3. Iterative reconstruction methods with angular dependence of frequency content from 2 and 3	WP4	Wed 02/10/24	Mon 30/12/24
502	4.4. Implementation of various dose-map reconstruction programs o	WP4	Wed 03/04/24	Wed 02/07/25
503	**PA2 Yrs 3-5**	**WP4**	**Fri 29/09/23**	**Sat 02/10/27**
530	**Reporting/ Milestones**	**WP4**	**Mon 01/04/24**	**Thu 30/09/27**
531	**Milestones**	**WP4**	**Mon 01/04/24**	**Thu 30/09/27**
532	**PA1 yrs1&2**	**WP4**	**Mon 01/04/24**	**Mon 30/09/24**
533	**M4.1 Geant4 simulations of beam energy deposition profile**	WP4	Mon 01/04/24	Mon 01/04/24
534	**M4.2 Acoustic sensor array design**	WP4	Mon 30/09/24	Mon 30/09/24
535	**PA2 yrs 3-5**	**WP4**	**Thu 02/04/26**	**Thu 30/09/27**
536	**M4.3 Iterative reconstruction methods**	WP4	Thu 02/04/26	Thu 02/04/26
537	**M4.4 Integration of ultrasonic array with radiobiology station**	WP4	Wed 30/09/26	Wed 30/09/26
538	**M4.5 LhARA ion-acoustic test results**	WP4	Thu 30/09/27	Thu 30/09/27



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2.5 Work package 5: Novel end-station development

Objectives

The principal objective (**O5.n**) for *Work package 5: Novel end-station development* is:

O5.1: Through peer-group consultation, produce detailed specifications and designs for the *in-vitro* and *in-vivo* end stations, the associated dosimetry and the beam diagnostics necessary to characterise the beam delivered to the end stations.

Alternative technologies to the ion-acoustic technique under development in Work Package 4 will be explored to ensure the beam delivered to the biological sample is fully characterised. Careful consideration will be given to appropriate automation and feedback to the accelerator so that an advanced, robust, and optimised solution is identified with capabilities in terms of precision beam delivery, environment control, and sample throughput that is unlike anything that is currently available.

Tasks

The objective defined above will be delivered through the following set of tasks:

- Design LhARA automated cell dish handling and environmental system via user-community consultation. De-risk key end station components though experimental measurements at Birmingham.

- Assessment of current beam monitoring technology and identification of the R&D required to deliver the diagnostic systems for LhARA
- Development of the design of a test facility at Birmingham capable of delivering kGy/s for use to prove instrumentation and diagnostics developed for LhARA in the Preconstruction Phase.

Resources

The resources to support Work Package 5: Novel end-station development are summarised in table 9.

Table 9: Resources required to execute Work Package 5.

LhARA WP5: Novel end station development	**R. McLauchlan, T. Price, C. Welsch**					**04/10/2022**
	Year 1		**Year 2**		**Total**	
Staff	**Fraction**	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
All						
BHM Physics						
BHM-Phys-NoOH	0.2	8.90	0.2	8.90	0.4	17.80
IC NHS HC Trust						
IC-NHS-HC-Trst	0.2	22.00	0.2	22.00	0.4	44.00
Liverpool Physics						
Liv-Phys-PDRA	0.5	61.50	0.5	61.50	1	123.00
Cost of risk mitigation, staff (not yet implemented):						
Staff total:	0.9	**92.40**	**0.9**	**92.40**	**1.8**	**184.80**
Non-staff		**£k**		**£k**		**£k**
All						
Equipment total:						
Inflation:						
User consultation meetings		5.00		5.00		10.00
Cyclotron accesss costs		6.00		6.00		12.00
Consumables		7.50		7.50		15.00
Travel		4.00		4.00		8.00
Cost of risk mitigation, equipment (not yet implemented):						
Working margin:						
Contingency, equipment:						
Contingency, CG staff:						
Contingency, all staff:						
Total:		**114.90**		**114.90**		**229.80**

We request 20% of both Dr. Price's and Dr. McLauchlan's time to lead the Work Package. In addition, we require a PDRA funded at 0.5 FTE with matched funding from University of Liverpool, and £15k consumables to develop the beam monitoring technologies identified in WP5. Beam line developments, integration, end-station component testing, and machine operation for beam-monitoring technologies at the University of Birmingham will be led by Dr Price and supported by the rest of the cyclotron team including Dr. C. Wheldon and Prof. T. Wheldon. We request £10k to allow the organisation of three consultation meetings on the end-station requirements over the 24 months to specify user requirements and £15k to allow initial designs and tests to be conducted on end-station and beam line components. Access for users to the cyclotron will be at the discounted research rate of £1.2k/day and we include 10 days of access at a total of £12k. The cyclotron facility will contribute one in kind day for each two days funded on the project up to a maximum of five in kind days.

Gantt chart and principal milestones

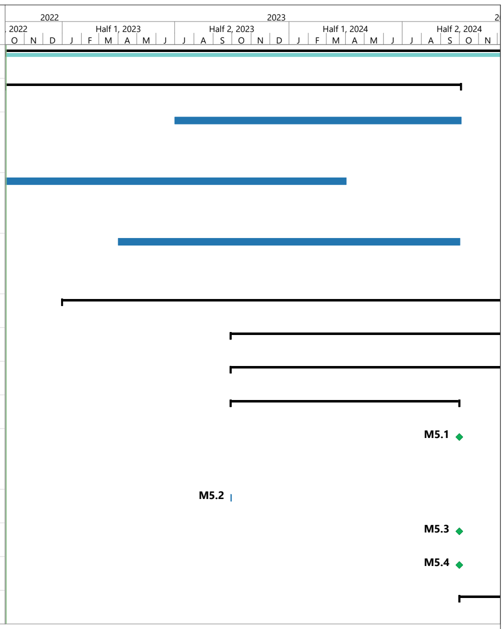
The milestones (**M5.n**) identified to monitor progress towards the objective defined above are:

- **M5.1** (month 6): Initial report on the user requirements for the *in-vitro* and *in-vivo* end stations. An initial parameter list and end-station specification will be given;
- **M5.2** (month 12): Report on the beam-monitoring technology for LhARA. The report will include an options analysis and discussion of cost and R&D requirements.
- **M5.3** (month 18): Second report on the user requirements for the *in-vitro* and *in-vivo* end stations. The report will contain detailed specifications, analysis of layout options, and initial designs for key components.

The programme of work for Workpackage 5 is shown in table 10.

Table 10: Gantt chart showing the programme of work for Work Package 5.

ID	Task Name	Work Package	Start	Finish	Notes
539	**WP5 Novel End station Development**	**WP5**	**Sat 01/10/22**	**Fri 01/10/27**	
540	**PA1 yrs1&2**	**WP5**	**Sat 01/10/22**	**Thu 03/10/24**	
541	Task 5.1 : Evaluate requirements for and design system to provide, suitable cell handling and environmental control.	WP5	Sat 01/07/23	Thu 03/10/24	
542	Task 5.2 Engage with cellular imaging community to assess end-station space and supporting infrastructure requirements.	WP5	Sat 01/10/22	Mon 01/04/24	
543	Task 5.3 De-risk key end station components though experimental measurements at Birmingham.	WP5	Sat 01/04/23	Tue 01/10/24	
544	**PA2 yrs3-5**	**WP5**	**Sun 01/01/23**	**Fri 01/10/27**	
549	**Reporting / Milestones**	**WP5**	**Fri 29/09/23**	**Fri 01/10/27**	
550	**Milestones**	**WP5**	**Fri 29/09/23**	**Fri 01/10/27**	
551	**PA1 yrs1&2**	**WP5**	**Fri 29/09/23**	**Tue 01/10/24**	
552	**M5.1. Design LhARA automated cell dish handling and environmental system**	WP5	**Tue 01/10/24**	**Tue 01/10/24**	**M5.1**
553	**M5.2. End-station user-community consultation - interim review**	WP5	Fri 29/09/23	Fri 29/09/23	**M5.2**
554	**M5.3. End-station user-community consultation**	WP5	**Tue 01/10/24**	**Tue 01/10/24**	**M5.3**
555	**M5.4. End-station component testing at Birmingham**	WP5	**Tue 01/10/24**	**Tue 01/10/24**	**M5.4**
556	**PA2 yrs3-5**	**WP5**	**Tue 01/10/24**	**Fri 01/10/27**	



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2.6 Work package 6: Design and integration

Objectives

During the 24-month Preliminary Activity the principal objective of *Work package 6: Design and integration* is the preparation of the conceptual design of the LhARA facility. Therefore, the work to be carried out under Work Package 6 includes the design and evaluation of the accelerator lattice, the specification of the required instrumentation, and initial consideration of their implementation and the necessary integration engineering.

The development of the Gabor lenses is the subject of WP3. To mitigate the risk that the Gabor-lens solution will not be completed in time, WP6 will develop an alternative solution based on solenoid magnets. The alternative solution will include an electromagnetic Wien filter for ion-species selection.

WP6 will evaluate the radiation protection and shielding requirements to inform the design of the building for the LhARA facility. Mechanical design, including the support for accelerator elements, in particular for the vertical arcs for *in-vitro* stations, will be addressed.

The challenging, novel FFA for the Stage 2, which will allow variable energy extraction will be designed. The Magnetic Alloy (MA) RF cavity system (the current baseline) for the FFA will be designed. Alternative swept-frequency RF systems will be considered and compared with the baseline.

WP6 will also encompass the design of the vacuum system as well as specification of the controls, electrical and RF engineering, beam diagnostics, technical services and the safety system design. The design of the facility will pay close attention to environmental sustainability.

The work of WP6 will inform the completion of the Conceptual Design Report (CDR) for the LhARA facility by the end of year 2. The work will be carried by the personnel from Universities and STFC, mainly from the Daresbury Laboratory (DL), as shown in the resource table 11.

Task objectives and deliverables

The objective (**O6.n**) of WP6 and the associated milestones (Ms) is:

- **O6.1**: Conceptual design of the LhARA facility, the accelerator systems and their integration with the source and the end stations. The conceptual design will encompass:
    1. Lattice optimisation, aperture estimation, parameter list and schematic diagram update;
    2. Preliminary design of the MA RF cavity;
    3. Preliminary design of the FFA magnet;
    4. Preliminary design of a solenoid capture and focusing system to mitigate the risks associated with WP3;
    5. Preliminary design of the bulk shielding, beam dump and radioprotection requirements;
    6. Preliminary design of the diagnostic system;
    7. Preliminary design of the control and feedback systems;
    8. Mechanical design of accelerator system and integration;
    9. Preliminary design of the building and infrastructure requirements;
    10. Preliminary design of the vacuum system;
    11. Preliminary design of the mechanical supports including the vertical arc;
    12. Estimation of the power consumption and cooling requirements;
    13. Finalise the Conceptual Design (all systems);
    14. Complete contributions to LhARA CDR (24 months).

Resources

The resources to support Work Package 6: Design and integration are summarised in table 11.

Gantt chart and principal milestones

The schedule and principle milestones for work package 6 in the first 24 month preliminary activity are shown in table **??** as a Gantt chart. The milestones (**M6.n** are summarised below.

- **M6.1** (month 6): Early review of R&D work towards LhARA CDR

Table 11: Resources required to execute Work Package 6.

LhARA WP6 Design and integration	N. Bliss, J. Pasternak					04/10/2022
	Year 1		Year 2		Total	
Staff	**Fraction**	**£k**	**Fraction**	**£k**	**Fraction**	**£k**
CDR and conceptual design development						
Imperial Physics						
IC-Phys-PDRA-1	0.5	86.81	0.5	86.81	1	173.62
RHUL Physics						
RHUL-PDRA-1	0.5	87.5	0.5	87.5	1	175
CDR and technical design studies						
STFC Technical						
STFC WP management	0.2	20	0.25	25	0.45	45
Mechanical engineering design specification	0.5	50	0.8	80	1.3	130
Electrical engineering design specification	0.05	5	0.55	55	0.6	60
Controls specification	0.05	5	0.25	25	0.3	30
Technical services specification			0.4	40	0.4	40
Vacuum specification			0.2	20	0.2	20
Radiation Protection Advisor	0.02	2.5	0.08	7.5	0.1	10
Cost of risk mitigation, staff (not yet implemented):						
Staff total:	1.825	**256.81**	**3.525**	**426.81**	**5.35**	**683.62**
Non-staff		**£k**		**£k**		**£k**
CDR and conceptual design development						
Software		2.50		2.50		5.00
CDR and technical design studies						
Equipment total:		**2.50**		**2.50**		**5.00**
Inflation:						
Consumables		3.00		3.00		6.00
Travel		4.00		4.00		8.00
Cost of risk mitigation, equipment (not yet implemented):						
Working margin:						
Contingency, equipment:						
Contingency, CG staff:						
Contingency, all staff:						
Total:		**266.31**		**436.31**		**702.62**

- **M6.2** (month 12): Interim review of R&D work towards LhARA CDR
- **M6.3** (month 18): Final review of R&D work towards LhARA CDR

The work will culminate with the delivery of the overarching deliverable (**D1.4**) of the CDR for LhARA and the LhARA contributions to the ITRF CDR.

The programme of work for Workpackage 6 is shown in table 12.

ID	Task Name	Work Package	Start
558	**WP6 System design**	**WP6**	**Mon 03/10/22**
559	**Year 1&2**	**WP6**	**Mon 03/10/22**
560	1. Lattice optimisation, aperture estimation, parameter list and schematic dia	WP6	Mon 03/10/22
561	2. Preliminary design of the MA RF cavity	WP6	Wed 01/02/23
562	3. Preliminary design of the FFA magnet	WP6	Wed 01/02/23
563	4. Preliminary design of the mitigating solenoid	WP6	Wed 01/02/23
564	5. Preliminary design study of bulk shielding, beam dump and radioprotection requirements	WP6	Mon 27/11/23
565	6. Preliminary design of the diagnostic system	WP6	Wed 01/02/23
566	7. Preliminary design of the control and feedback systems	WP6	Mon 02/10/23
567	8. Mechanical design of accelerator system and integration	WP6	Wed 01/02/23
568	9. Preliminary design of the building and infrastructure requirements	WP6	Mon 02/10/23
569	10. Preliminary design of the vacuum system	WP6	Mon 30/10/23
570	11. Preliminary design of the mechanical supports including the vertical arc	WP6	Mon 08/01/24
571	12. Estimation of the power consumption and cooling requirements	WP6	Mon 27/11/23
572	13. Finalise the Conceptual Design (all systems)	WP6	Wed 03/04/24
573	14. Write CDR	WP6	Thu 25/07/24
574	**Year 3-5**	**WP6**	**Tue 01/10/24**
606	**Reporting / Milestones**	**WP6**	**Mon 03/10/22**
607	Internal Reporting / input to LhARA progress reports	WP6	Mon 03/10/22
608	Milestones	WP6	Mon 03/04/23
609	**year 1&2**	**WP6**	**Mon 03/04/23**
610	**M6.1: Early review of R&D work towards LhARA CDR (6 months)**	WP6	**Mon 03/04/23**
611	**M6.2: Interim review of R&D work towards LhARA CDR (12 months)**	WP6	**Mon 02/10/23**
612	**M6.3: Final review of R&D work towards LhARA CDR (18 months)**	WP6	**Tue 02/04/24**

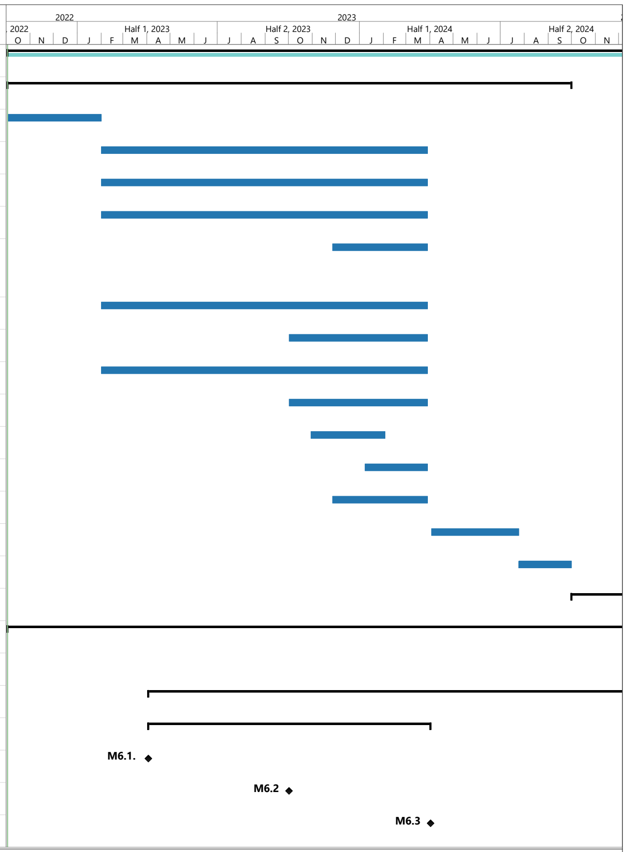

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Table 12: Gantt chart showing the programme of work for Work Package 6.

3 Overview of Preliminary Activity project costs

The costing summarised below has been obtained on the following basis:

- The capital and staff costs have been estimated in calendar year 2022 based on input from each institution. Inflation has not been included.
- Each staff member or role has been asigned a unique identifier is in order to preserve anonymity. A confidential staff database is being maintained to establish the correspondence between individuals and the unique identifiers.
- VAT (at the rate of 20%) is included in all equipment costs by work package; the total cost of VAT is summarised by work package above.
- The costs contain no working margin oor contingency.

Table 13: Overview of project cost.

LhARA Preliminary Activity and Pre-cnstruction Project cost overview A. Giacca. K. Long, J. Parsons, C. Whyte

	Work package		2022/23		2023/24		Total	
Id	*Name*		*Fraction*	*£k*	*Fraction*	*£k*	*Fraction*	*£k*
Staff effort, summary by institute								
1	***LhARA Project Management***							
		Strathclyde Physics	0.50	80.00	0.50	80.00	1.00	160.00
2	***Laser-driven proton and ion source***							
		Imperial Physics	0.43	73.17	0.50	85.48	0.93	158.66
		Lancaster Physics	0.55	67.50	0.55	67.50	1.10	135.00
		Queen's Physics	0.05	6.50	0.05	6.50	0.10	13.00
		Strathclyde Physics	0.60	75.00	0.60	75.00	1.20	150.00
3	***Proton and ion capture***							
		Manchester Physics	0.10	20.75	0.10	20.75	0.20	41.50
		Swansea Physics	1.10	126.59	1.10	126.59	2.20	253.18
4	***ionacoustic Imaging***							
		ICR, Radiotherapy and Imaging	0.10	20.95	0.10	20.95	0.20	41.90
		STFC-PPD	0.04	6.00	0.04	6.00	0.08	12.00
		UCL, Biomedical Engineering	0.05	8.75	0.05	8.75	0.10	17.50
5	***Novel end station development***							
		BHM Physics	0.20	8.90	0.20	8.90	0.40	17.80
		IC NHS HC Trust	0.20	22.00	0.20	22.00	0.40	44.00
		Liverpool Physics	0.50	61.50	0.50	61.50	1.00	123.00
6	***Design and integration***							
		Imperial Physics	0.50	86.81	0.50	86.81	1.00	173.62
		RHUL Physics	0.50	87.50	0.50	87.50	1.00	175.00
		STFC Technical	0.83	82.50	2.53	252.50	3.35	335.00
	Staff totals		***6.24***	***834.42***	***8.02***	***1016.73***	***14.26***	***1851.15***
Non-staff cost summary								
1	***LhARA Project Management***			6.50		6.50		13.00
2	***Laser-driven proton and ion source***			67.50		117.50		185.00
3	***Proton and ion capture***			76.00		38.00		114.00
4	***ionacoustic Imaging***			15.00		12.00		27.00
5	***Novel end station development***			22.50		22.50		45.00
6	***Design and integration***			9.50		9.50		19.00
	Non-staff totals			***197.00***		***206.00***		***403.00***
Total staff and non-staff by work package								
1	***LhARA Project Management***		0.50	86.50	0.50	86.50	1.00	173.00
2	***Laser-driven proton and ion source***		1.63	289.67	1.70	351.98	3.33	641.66
3	***Proton and ion capture***		1.20	223.34	1.20	185.34	2.40	408.68
4	***ionacoustic Imaging***		0.19	50.70	0.19	47.70	0.38	98.40
5	***Novel end station development***		0.90	114.90	0.90	114.90	1.80	229.80
6	***Design and integration***		1.83	266.31	3.53	436.31	5.35	702.62
Grand totals				**1031.42**		**1222.73**		**2254.15**

4 Staff effort

Table 14 presents a list by institute and task of the effort required to execute the programme defined above.

5 Deliverables and milestones

Lead authors: C. Whyte

References

[1] "The Laser-hybrid Accelerator for Radiobiological Collaboration institute list." https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Research/DesignStudy/2021-05-14-Institute-list-v8.pdf, May, 2021. Accessed: 2021-12-22.

[2] "The Laser-hybrid Accelerator for Radiobiological Collaboration institute slide." https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Research/DesignStudy/2021-05-11-Institute-slide-v8.pdf, May, 2021. Accessed: 2021-12-22.

[3] The LhARA collaboration, "The Laser-hybrid Accelerator for Radiobiological Applications: R&D proposal for the preliminary, pre-construction phases," Tech. Rep. CCAP-TN-10, The Centre for the Clinical Application of Particles, Imperial College London, 2022. https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-10.pdf.

[4] "Ion Therapy Research Facility." https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Research/DesignStudy/Proposals/2021/2021-06-15-ITRF-1-page-Final.pdf, June, 2021. Cover page submitted to support the full proposal.

[5] "Infrastructure Fund projects." https://www.ukri.org/what-we-offer/creating-world-class-research-and-innovation-infrastructure/funded-infrastructure-projects/, June, 2022. Projects funded from the UKRI Infrastructure Fund, 2022.

[6] "Infrastructure Fund projects." Link to be provided, Month to be provided, 2022. ITRF project management document.

Table 14: Overview of staff effort and cost.

Staff	Year 1 Fraction	Year 1 £k	Year 2 Fraction	Year 2 £k	Total Fraction	Total £k
BHM Physics						
BHM-Phys-NoOH						
LhARA: Novel end station development	0.20	8.90	0.20	8.90	0.40	17.80
Total	**0.20**	**8.90**	**0.20**	**8.90**	**0.40**	**17.80**
IC NHS HC Trust						
IC-NHS-HC-Trst						
LhARA: Novel end station development	0.20	22.00	0.20	22.00	0.40	44.00
Total	**0.20**	**22.00**	**0.20**	**22.00**	**0.40**	**44.00**
ICR, Radiotherapy and Imaging						
ICR-Stf-1						
LhARA: ionacoustic Imaging	0.05	11.00	0.05	11.00	0.10	22.00
ICR-Stf-2						
LhARA: ionacoustic Imaging	0.05	9.95	0.05	9.95	0.10	19.90
Total	**0.10**	**20.95**	**0.10**	**20.95**	**0.20**	**41.90**
Imperial Physics						
IC-Phys-PDRA-1						
LhARA: Design and integration	0.50	86.81	0.50	86.81	1.00	173.62
IC-Phys-Stf-1						
LhARA: Laser-driven proton and ion source	0.43	73.17	0.50	85.48	0.93	158.66
Total	**0.93**	**159.98**	**1.00**	**172.29**	**1.93**	**332.28**
Lancaster Physics						
Lanc-Phys-PDRA-1						
LhARA: Laser-driven proton and ion source	0.50	60.00	0.50	60.00	1.00	120.00
Lanc-Phys-Stf-1						
LhARA: Laser-driven proton and ion source	0.05	7.50	0.05	7.50	0.10	15.00
Total	**0.55**	**67.50**	**0.55**	**67.50**	**1.10**	**135.00**
Liverpool Physics						
Liv-Phys-PDRA						
LhARA: Novel end station development	0.50	61.50	0.50	61.50	1.00	123.00
Total	**0.50**	**61.50**	**0.50**	**61.50**	**1.00**	**123.00**
Manchester Physics						
Man-Phys-Stf-1						
LhARA: Proton and ion capture	0.10	20.75	0.10	20.75	0.20	41.50
Total	**0.10**	**20.75**	**0.10**	**20.75**	**0.20**	**41.50**
Queen's Physics						
Qns-Phys-Stf-1						
LhARA: Laser-driven proton and ion source	0.05	6.50	0.05	6.50	0.10	13.00
Total	**0.05**	**6.50**	**0.05**	**6.50**	**0.10**	**13.00**
RHUL Physics						
RHUL-PDRA-1						
LhARA: Design and integration	0.50	87.50	0.50	87.50	1.00	175.00
Total	**0.50**	**87.50**	**0.50**	**87.50**	**1.00**	**175.00**
STFC Technical						
Controls specification						
LhARA: Design and integration	0.05	5.00	0.25	25.00	0.30	30.00
Electrical engineering design specification						
LhARA: Design and integration	0.05	5.00	0.55	55.00	0.60	60.00
Mechanical engineering design specification						
LhARA: Design and integration	0.50	50.00	0.80	80.00	1.30	130.00
Radiation Protection Advisor						
LhARA: Design and integration	0.03	2.50	0.08	7.50	0.10	10.00
STFC WP management						
LhARA: Design and integration	0.20	20.00	0.25	25.00	0.45	45.00
Technical services specification						
LhARA: Design and integration	0.00	0.00	0.40	40.00	0.40	40.00
Vacuum specification						
LhARA: Design and integration	0.00	0.00	0.20	20.00	0.20	20.00
Total	**0.83**	**82.50**	**2.53**	**252.50**	**3.35**	**335.00**
STFC-PPD						
STFC-PPD-Stf-1						
LhARA: ionacoustic Imaging	0.04	6.00	0.04	6.00	0.08	12.00
Total	**0.04**	**6.00**	**0.04**	**6.00**	**0.08**	**12.00**
Strathclyde Physics						
Strathclyde-Phys-PDRA-1						
LhARA: Laser-driven proton and ion source	0.50	61.50	0.50	61.50	1.00	123.00
Strathclyde-Phys-Stf-1						
LhARA: LhARA Project Management	0.50	80.00	0.50	80.00	1.00	160.00
Strathclyde-Phys-Stf-2						
LhARA: Laser-driven proton and ion source	0.10	13.50	0.10	13.50	0.20	27.00
Total	**1.10**	**155.00**	**1.10**	**155.00**	**2.20**	**310.00**
Swansea Physics						
Swns-Phys-PDRA-1						
LhARA: Proton and ion capture	1.00	107.70	1.00	107.70	2.00	215.40
Swns-Phys-Stf-1						
LhARA: Proton and ion capture	0.10	18.89	0.10	18.89	0.20	37.78
Total	**1.10**	**126.59**	**1.10**	**126.59**	**2.20**	**253.18**
UCL, Biomedical Engineering						
UCL-Stf-1						
LhARA: ionacoustic Imaging	0.05	8.75	0.05	8.75	0.10	17.50
Total	**0.05**	**8.75**	**0.05**	**8.75**	**0.10**	**17.50**
Grand total	***6.24***	***834.42***	***8.02***	***1016.73***	***14.26***	***1851.15***