SERVICES & FACILITIES ANNUAL REPORT - FY April 2014 to March 2015

SERVICE	FUNDING	AGREEMENT	ESTABLISHED as S&F	TERM
Argon Isotope Facility (673 HDU per annum)	Block	R8/H10/77	1994	2014-?

TYPE OF SERVICE PROVIDED

The temporal resolution of the stratigraphic record, the only account of the 4.6 billion years of geological history, is the primary control on the complexity of questions scientists can ask about the Earth, its evolution and resultant habitability. As a consequence of the scientific pursuit to temporally dissect the geological record and decode Earth history, the NERC Argon Isotope Facility (AIF) was established through community demand nearly 20 years ago. Today the AIF is regarded as a leading international authority in geochronology, houses the most extensive range of analytical tools dedicated to the $^{40}Ar/^{39}Ar$ technique throughout Europe, and has the capability of dating K-bearing materials that were formed during Solar System accretion or rocks and minerals erupted during historical times.

The AIF has spent many years fine-tuning noble gas mass spectrometer techniques and different approaches to high-precision $^{40}Ar/^{39}Ar$ geochronology to give the UK user community access to a state-of-the-art $^{40}Ar/^{39}Ar$ dating laboratory. Although AIF dates rocks from every Era of Earth History, we as a NERC Facility, specifically *aim to define the template for collection of robust, accurate and highly precise $^{40}Ar/^{39}Ar$ ages from a variety of geologically young materials* to support NERC science. For example, AIF establish dates and rates for the expansion of humans from Africa (e.g., Adler *et al*., 2014), facilitates temporal integration of palaeoclimate signals to allow investigation of past global climate change (e.g., Mark *et al*., 2014), determine timescales and frequencies of volcanic activity and super-eruptions to mitigate risk to the general populous (e.g., Hicks *et al*., 2012), reconstruct timescales of fluid-rock interaction with respect to the mineralisation of mineable resources (e.g., Rice *et al*., 2005) and generation of hydrocarbons (e.g., Mark *et al*., 2010). As such, the Facility *ethos* is strongly aligned with the evolving NERC Strategy with output having direct societal and economic benefits to the UK and beyond. However, as a versatile Facility that prides itself on being responsive to community demand, the AIF maintains scientific capability and intellectual leadership in deep time geochronology, for example, in studies of mass extinctions (e.g., Renne *et al*., 2013), geochemical evolution of the atmosphere and oceans (e.g., Parnell *et al*., 2010; 2014), changes to ocean circulation (e.g., Dalziel *et al*., 2013), dating of ancient volcanic eruptions (e.g., Ellis *et al*., 2012), geomagnetism and inner core processes (e.g., Mark *et al*., in review), resolution of the interplay between climate and tectonics (e.g., Henderson *et al*., 2011).

On the international stage, the AIF also leads UK $^{40}Ar/^{39}Ar$ efforts in the EarthTime initiative, conducts community service in the preparation of standards (e.g., Morgan *et al*., 2014), is making pioneering measurements to improve our understanding of the uncertainties associated with the $^{40}Ar/^{39}Ar$ approach (e.g., Morgan *et al*. 2011) whilst constantly developing novel approaches to noble gas mass spectrometry (e.g., Mark *et al*., 2009) and refining the constants we rely on for radio-isotopic dating (e.g., Mark *et al*., 2011) and even everyday life (e.g., the Boltzmann constant and Kelvin temperature-scale, de Podesta *et al*., 2013). The AIF is internationally established as a cutting-edge dating facility, due to the expertise and experience of AIF personnel, the quality of its scientific output (peer-reviewed publications, PhD theses, conference presentations), technical innovation and training of chronology-literate scientists (references listed in Annex 1a).

HOST INSTITUTION & FACILITY MANAGEMENT

The Scottish Universities Environmental Research Centre (SUERC) hosts the AIF, which benefits from complementary in-house technical and academic expertise, in particular from noble gas, stable and radiogenic isotope laboratories. The AIF Head of Facility is Dr. Darren Mark, scientific support is provided by Dr. Dan Barfod, and technical support by Mr. James Imlach and Mr. Ross Dymock. Facility science quality is maintained by NIGFSC. In addition to the host centre, note the AIF is reliant on nuclear reactor facilities for sample irradiation (Annex 15).

ANNUAL TARGETS AND PROGRESS TOWARDS THEM

The 2014-2015 year has seen continuous output and improved performance from the AIF, despite significant on-going NERC budget cuts to the Facility and an overall climate of uncertainty regarding the future structure of NERC, the governance of Facilities and status of BGS. Despite this, AIF had an excellent intake of high quality projects and we have performed more analyses on NERC-funded projects than in any previous year whilst continuing to deliver high-quality publications (AIF citations almost doubled) and training. The approved project programme is commensurate with allocated resource highlighting the consistent demand for Facility access. The AIF continues to obtain grants, funding and commissions that co-funds staff and equipment, which along with internal SUERC-funding makes up the deficit from NERC funding cuts. There is no Facility backlog and the time taken from sample receipt to data return to PI remains on average 6 months (which includes a 3 month irradiation period). The Facility was awarded a Capital Grant from NERC in 2014 to upgrade the electronics on the MAP 215-50.

SCORES AT LAST REVIEW (each out of 5)		Date of Last Review:		
Need	**Uniqueness**	**Quality of Service**	**Quality of Science & Training**	**Average**
5	4.5	4.5	4.5	4.63

CAPACITY of HOST ENTITY FUNDED by S&F	Staff & Status	Next Review (March)	Contract Ends (31 March)
100%	Dr D.F. Mark (Head of Facility, Grade 9, Head, SRF, R1A, 50% FTE) Dr D. N. Barfod (PDRA, Grade 7, PDRA, R1A, 100% FTE) Mr J.G. Imlach (Technician, Grade 6, 100% FTE) Mr. R. Dymock (Technician, Grade 5, 100% FTE)	??	??

FINANCIAL DETAILS: CURRENT FY						
Total Resource Allocation	**Unit Cost (half day units, 673 per annum)**			**Capital Expend**	**Income**	**Full Cost**
	Unit 1	**Unit 2**	**Unit 3**			
£247.5k	£0.430k			£42k	£0k	£308.64k

FINANCIAL COMMITMENT (by year until end of current agreement) £k				
2014-15 £247.5k	**2015-16** ??			

STEERING COMMITTEE	Independent Members	Meetings per annum	Other S&F Overseen
NIGFSC	8	2	NIGL, ICSF & CIAF

APPLICATIONS: DISTRIBUTION OF GRADES (current FY — 2014/15)													
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**	**R***	**Pilot**
NERC Grant projects*												1	
Other academic				1							2	2	
Students			2	1								2	
TOTAL			2	2							2	5	

APPLICATIONS: DISTRIBUTION OF GRADES (per annum average previous 3 financial years —2011/2012, 2012/2013 & 2013/2014)													
	10	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**	**R***	**Pilot**
NERC Grant projects*			0.33	1									
Other academic	0.33		1	1									
Students			0.33	1.33	0.33	0.33							
TOTAL	0.33		1.66	3.33	0.33	0.33							

PROJECTS COMPLETED (current FY – 2014/15)												
	10 (α5)	**9**	**8 (α4)**	**7**	**6 (α3)**	**5 (α2)**	**4**	**3 (α1)**	**2**	**1 (β)**	**0 (Reject)**	**Pilot**
NERC Grant projects*			1	1								
Other Academic			2									
Students				1								

Project Funding Type (current FY – 2014/15) (select one category for each project)											
Grand Total	**Infrastructure**					**PAYG**					
	Supplement to NERC Grant *	**PhD Students**		**NERC Centre**	**Other**	**NERC Grant***	**PhD Students**		**NERC Centre**	**Other**
		NERC	**Other**				**NERC**	**Other**		
32	4	1	16	0	11	0	0	0	0	0

Project Funding Type (per annum average previous 3 financial years - 2011/2012, 2012/2013 & 2013/2014)											
Grand Total	**Infrastructure**					**PAYG**					
	Supplement to NERC Grant *	**PhD Students**		**NERC Centre**	**Other**	**NERC Grant***	**PhD Student**		**NERC Centre**	**Other**
		NERC	**Other**				**NERC**	**Other**		
24	5	4.5	8.5	1	5	0	0	0	0	0

User type (current FY – 2014/15) (include each person named on application form)				
Academic	**NERC Centre**	**NERC Fellows**	**PhD Students**	**Commercial**
32	0	1	17	0
User type (per annum average previous 3 financial years - 2011/2012, 2012/2013 & 2013/2014)				
Academic	**NERC Centre**	**NERC Fellows**	**PhD Students**	**Commercial**
22.66	1.33	0.33	13	0

OUTPUT & PERFORMANCE MEASURES (current year)										
Publications (by science area & type) (calendar year 2014)										
SBA	**ES**	**MS**	**AS**	**TFS**	**EO**	**Polar**	**Grand Total**	**Refereed**	**Non-Ref/Conf. Proc.**	**PhD Theses**
3	16	0	0	0	0	0	19	11	3	5

Distribution of Projects (by science areas) (FY 2014/15)							
Grand Total	**SBA**	**ES**	**MS**	**AS**	**TFS**	**EO**	**Polar**
32	3	29	0	0	0	0	0

OUTPUT & PERFORMANCE MEASURES (per annum average previous 3 years)										
Publications (by science area & type) (Calendar years 2011, 2012 & 2013)										
SBA	**ES**	**MS**	**AS**	**TFS**	**EO**	**Polar**	**Grand Total**	**Refereed**	**Non-Ref/Conf. Proc.**	**PhD Theses**
0.67	20.67	0	0	0	0	0	21.34	16	2.67	2.67

Distribution of Projects (by science areas) (FY 2011/2012, 2012/2013 & 2013/2014)							
Grand Total	**SBA**	**ES**	**MS**	**AS**	**TFS**	**EO**	**Polar**
24	2	22	0	0	0	0	0

Distribution of Projects by NERC strategic priority (current FY 2014/15)							
Grand Total	**Climate System**	**Biodiversity**	**Earth System Science**	**Sustainable Use of Natural Resources**	**Natural Hazards**	**Environment, Pollution & Human Health**	**Technologies**
32	1.7	2.3	16	1.5	9.5	0	1

**Either Discovery Science (Responsive Mode) or Strategic Science (Directed Programme) grants*

NOTE: All metrics should be presented as whole or part of whole number NOT as a %

OVERVIEW & ACTIVITIES IN FINANCIAL YEAR (2014/15)

Project throughput: AIF have completed 8 projects, made 6567 mass spectrometer runs for unknowns out of 17329 runs overall. Within the past year the AIF has worked on 32 different projects, involving 26 PIs from 19 different institutions including training and supervision of 24 PhD students.

Laboratory performance/updates

- ARGUS: The ARGUS line has been completely re-configured and is fully operational. In addition, a new Photon Machines Fusions automated CO_2 laser system was installed and fully integrated with the automated operating software. The system is optimized for step heating of geological materials, with sample aliquots ranging up to 100 mg, ideal for young samples. The re-build incurred less than 30 days downtime (5% Facility capacity). Annex 1b shows step heating data for a biotite sample with efficient un-mixing of atmospheric from radiogenic components yielding an improvement in throughput and age precision.
- MAP-215: This 20 year old instrument experienced 3.5 months of downtime due to instabilities with electronics. This was a 15% loss of overall Facility capacity. Various software solutions and hardware reconfigurations circumvented some of the issues, but highlighted the increasing need to refurbish the ageing electronics (2015-2016, see below). Despite this, the MAP 215-50 continues to produces excellent quality data when working at its optimum (as good as any machine in any other laboratory).
- HELIX-SFT: Several technical issues were resolved during early-mid 2014 including replacement of the source connection electronic loom, replacement of the multiplier and upgrades and modification of control software for better peak location and centering routines. Late-2014: HELIX-SFT data are proving to be spectacular, for example a new preliminary age for sanidine from the Campanian Ignimbrite of is comparable to the precision of ^{14}C at this age range but more accurate owing to the poor ^{14}C calibration in this age range (Annex 1c).
- Backgrounds for all AIF systems are at all time lows, which facilitates dating of the most problematic (young, low-K) samples. Ultra-low backgrounds for the new ARGUS line were permitted as SUERC internally funded the purchase of a new pumping system totalling *c*. £15,000 (full details Annex 1d). In an attempt to understand the impact of backgrounds and isobaric interferences on $^{40}Ar/^{39}Ar$ data, AIF are leading an international project with *BGC, OU, Curtin University & Vrije Universitiet* – paper in prep.

Project throughput with respect to NERC budget cuts: There is no Facility backlog with respect to NIGFSC-funded projects and average turnaround time remains 6-12 months (despite some mass spec. downtime). For example, the analyses for Pyle (IP/1506/1114) funded in the last NIGFSC round (Nov. 2014) were completed in February 2015. Despite the required downtime and continued NERC budget cuts, project throughput and capacity both remain at all time highs. This is a result of (1) SUERC internally funding the shortfall (£17.3k for 2014-2015) to AIF personnel and (2) the automation of all mass spectrometer systems which allows for absorption of laboratory downtime and further capacity to meet deadlines.

Indicators of esteem

- Publication led by Dr. Mark in top 5 most downloaded Quaternary Geochronology papers of 2014 (Mark *et al*., 2014, Young Toba Tuff).
- Geol. Soc. London Special Publication dedicated to advances in Ar/Ar dating published (Dr. Mark lead Editor).
- Tomkinson *et al*. (2013) published in *Nature Communications*, has been chosen to feature as part of a *Nature Communications* Earth science collection. The collection features a few select open access articles published in *Nature Communications* over the past two years that represent 'great examples of significant advances within their fields'.
- Dr Mark has been invited to the Editorial Board of Quaternary Geochronology.
- AIF staff continues to review both manuscripts in top peer-reviewed journals (e.g., Science, Nature, Geology, EPSL).
- AIF staff continues to review research grant proposals for NERC, Leverhulme, NSF and EPSRC.
- AIF and collaborators presented at several national/international conferences, including Goldschmidt, AGU, EGU & VMSG.

Outputs: 32 papers involving AIF personnel were published in international journals and 6 are currently in press. Additionally 7 are *sub judice*. A total of 27 conference abstracts were presented and 5 PhD theses where defended successfully.

New NERC funding activity (2013 onwards)

- A 500 ka environmental record from Chew Bahir, south Ethiopia: testing hypotheses of climate-driven human evolution, innovation, and dispersal (NERC SG funded, NE/KO11871/1, PI Henry Lamb) – awaiting NIGFSC application.
- Quaternary development of the Upper Aras and Kura catchments in NE Turkey, Georgia, Armenia: A context for early hominin occupation and dispersal (NERC SG in review, NE/N003675/1, PI Darrel Maddy).
- What was the scale of the tsunami generated by the Late Bronze Age eruption of Santorini and was it a factor in the Minoan decline? (NERC SG in review, NE/N004701/1, PI Dave Tappin).
- Why is the average elevation of the Arabian Swell > 1 km? (NERC NIG, in review, NE/N004353/1, PI Gareth Roberts).
- Greenland Ice-core Timescales (NERC Fellowship, in review, NE/M018962/1, PI Richard Staff).

Other business

- *Synergistic funding:* Dr. Mark continues to lead a £1.5M STFC-funded consortium that is examining the timing and mechanisms of fluid-rock interaction in rocks from Mars, primitive and processed asteroids. In addition Dr. Mark leads a UKSA CREST II technology grant to develop an $^{40}Ar/^{39}Ar$ dating instruments package (KHRONOS) for rover-based exploration and is Co-I on a series of UKSA and ESA grants. Dr. Mark is also Co-I on a Leverhulme-funded project 'Timing is everything: Anticipating future eruptive activity on Ascension Island' Note that funding and people who work with AIF as a part of these non-NERC projects contribute to shortfalls in NERC budgets and bring expertise and experience to the Facility, cementing our position as a world leading authority in $^{40}Ar/^{39}Ar$ geochronology. In addition, the equipment (e.g., diode lasers/$10^{13/14}$ ohm resistors) purchased by other funding streams are made available through the AIF to the UK NERC user community, furthering the unique capability the AIF offers to help ensure the Facility and UK science remains state-of-the-art and world-leading.
- Dr. Leah Morgan (formerly BGC and VU) spent time during the autumn with the ARGUS system to make fundamental metrological K and Ar measurements with the goal of improving the measurement uncertainties associated with $^{40}Ar/^{39}Ar$ geochronology. Because these ^{40}Ar and ^{40}K measurements are metrologically traceable and made on mineral standards used in $^{40}Ar/^{39}Ar$ geochronology, this work will have a direct impact on technique accuracy and permit a rigorous assessment of uncertainties in $^{40}Ar/^{39}Ar$ ages (*manuscript in prep.*). The work performed by AIF and Dr. Morgan will represent a *step-change* in the $^{40}Ar/^{39}Ar$ technique. Leah has since taken up a post at the USGS, Denver.
- New international standard (FCs-EK) now available to the international community from AIF. After rigorous testing the age of the standard has been shown to be indistinguishable from the previous generation standard (FC-2) at current measurement precision (Annex 1e).

Capital items: AIF received funding for electronics upgrade to MAP 215-50 to be installed 2015-2016 after AIF secured a contract with ProVac Services Ltd. (Crewe, UK) to conduct a full refurbishment.

SCIENCE HIGHLIGHTS

The timing and evolution of the Don Manuel igneous complex and porphyry copper system, Chile [Sparks, IP-1415-1113, PhD thesis and manuscript in prep.]: The Don Manuel igneous complex offers a unique opportunity to trace the magmatic evolution of a porphyry copper system. Primary magmatic features of the system are accessible due to the rapid exhumation rate in the Andes of central Chile. This work addresses the role and timing of magma mixing, magma degassing, and high temperature fluid alteration in ore formation. New $^{40}Ar/^{39}Ar$ ages on mafic dikes constrain the timing of magma emplacement in the complex and provide critical data for a PhD thesis. Igneous contacts, structures and textures indicative of magma mingling, mixing and hybridization are conspicuous at Don Manuel. These features along with the new $^{40}Ar/^{39}Ar$ data indicate the presence of contemporaneous mafic magma that may serve as the source of sulfur-rich gases in mineralization models. New $^{40}Ar/^{39}Ar$ ages for hydrothermal biotite associated with the potassic alteration and mineralization make Don Manuel the youngest system within the Miocene-Pliocene porphyry Cu-Mo belt in Chile. This work opens up new exploration targets across the region for mining having a direct economic impact to the region and mining industries.

Early Levallois technology and the Lower to Middle Paleolithic transition in the Southern Caucasus [Wilkinson, IP-1186-0510, published in Science]: The Lower to Middle Paleolithic transition (*c*. 400-200 ka) is marked by technical, behavioral, and anatomical changes among hominin populations throughout Africa and Eurasia. The replacement of bifacial stone tools, such as hand-axes, by tools made on flakes detached from Levallois cores documents the most important conceptual shift in stone tool production strategies since the advent of bifacial technology more than one million years earlier and has been argued to result from the expansion of archaic *Homo sapiens* out of Africa. Our data from Nor Geghi 1, Armenia, record the earliest synchronic use of bifacial and Levallois technology outside Africa and are consistent with the hypothesis that this transition occurred independently within geographically dispersed, technologically precocious hominin populations with a shared technological ancestry. The work potentially redefines our understanding of human evolution showing that technological advancement was occurring within Europe synchronous with Africa – there is no requirement for technology to have been transferred between continents. This contribution challenges current understanding about hominin evolution.

Indus Civilisation urban centers in northwest India were not sustained by a large Himalayan river [Gupta, IP-1267-1111, in review Science]: Urbanization in the Bronze age Indus Civilisation (*c*. 4.8-3.9 ka) has been linked to agricultural fertility provided by large Himalayan alluvial systems. However, numerous urban-scale sites are located far from extant Himalayan rivers. Palaeo-river channel traces observed near these sites were proposed as former large Himalayan rivers that sustained such centers. We report the discovery of a large buried fluvial system adjacent to the major Indus urban settlement at Kalibangan (Rajasthan, India). Isotopic fingerprinting ($^{40}Ar/^{39}Ar$ muscovite) demonstrates that a prior Sutlej river deposited this system, but dating of sand grains indicates that river flow terminated by *c*. 15 ka, considerably earlier than Indus occupation. A large Himalayan river did not sustain Indus centers in northwest India, implying adaption to more diverse environmental landscapes than previously considered. The work challenges paradigms that developing Indus civilizations required settlements close proximity to major river systems and requires a rethink concerning development of civilizations.

Constraining timescales of caldera formation and edifice growth at a young Ethiopian rift volcano [Pyle, IP-1506-1114 (NE/J500045/1), PhD thesis and manuscript in prep.]: Volcanoes of the Ethiopian Rift are among some of most dangerous in the world, with a history of young (<400 ka) explosive caldera-forming eruptions, and greater than 9 million people living within 30 km of an active volcano. Nevertheless, for many Ethiopian volcanoes the eruptive history is poorly constrained, and thus understanding of the size and frequency of past eruptions is extremely limited. To help address this knowledge gap we analysed seven separate eruptions from the Aluto volcano. Ages span from c. 300 ka to as young as 11 ka, and thus establish a timescale for large caldera-forming ignimbrite eruptions, advancing understanding of edifice growth rates and the timing of post-caldera volcanism. This study provides a valuable pilot study for the upcoming NERC-funded RiftVolc project. Although Aluto is considered to pose high volcanic hazard & risk, it is also home to the Aluto-Langano geothermal power station - the Ethiopian government plans to expand regional geothermal production and require a better understanding of the volcanic history of the region. This contribution has direct economic and societal impact.

FUTURE DEVELOPMENTS/STRATEGIC FORWARD LOOK

Laboratory: Updating of the MAP 215-50 electronic units (funding secured during last NERC capital award round) and to complement this, update of the extraction line and aged CO_2 laser (funding for which has been requested during this 2015 NERC capital call). Although 20 years old, with a small amount of further capital investment the MAP 215-50 system can be maintained to deliver high-quality data, especially for the dating of small samples (i.e., single crystals) ranging in age between the Quaternary and Precambrian. Science: In 2015-2016 the AIF will: (1) continue to be responsive to the user community across the breadth of NERC-remit science and will continue to focus on construction of chronologies for young geological events within the realms of climate change and human evolution. (2) Capitalise on previous NERC grant success - The Chew Bahir project. The Project involves deep drilling of lacustrine sediments at five globally significant early hominin sites in Kenya and Ethiopia, including Chew Bahir. The combined data allow comparison of 4 Ma of environmental change with the record of human and mammalian evolution, extinction, cultural innovation, and geographic dispersal. The data will be used to evaluate models of climatic and tectonic forcing of environmental processes and landscape resources, and will facilitate testing of hypotheses linking climate variability to human origins, evolution, population change, extinction, and dispersal from Africa into Eurasia. (3) Greenland ice core records demonstrate that climatic transitions can occur within decades and to further understand these abrupt climate changes, and any geographical leads and lags, it is important to correlate high-resolution terrestrial, marine and ice core archives from around the globe. This requires improved dating techniques and methods for correlation. Tephrochronology offers huge potential to correlate regional records, and to provide high-precision chronology to link global archives. Volcanic ash form horizons in a variety of settings, which can be used as temporal markers. Theoretically the tephra can be dated using the $^{40}Ar/^{39}Ar$ technique thereby placing direct temporal constraints on correlated palaeoclimate records. We will continue to develop methods for establishing accurate and high-precision $^{40}Ar/^{39}Ar$ constraints for fine-grained tephra (Annex 13). Training: This will remain a top priority. The AIF will continue to provide hands-on-experience to students and PDRAs. With respect to Quaternary Geochronology a key advance will be the construction of integrated multi-chronometer chronologies that allow for Bayesian modelling of age-depth profiles. We are planning a workshop and meeting to kick start this initiative, which has potential for tremendous synergy between different NERC Facilities. The AIF will also offer short courses in geochronology and noble gas mass spectrometry and feed directly into NERC DTP Training Schools. NERC Demand Management: SUERC has been sanctioned by the Demand Management review and as a consequence NERC activity led by the AIF (PI and Co-I) will now be constrained by the SUERC quota. Demand Management has serious implications for the way AIF operates and will long-term impact the Facilities ability to perform at its optimum on a platform of ever decreasing NERC Service & Facilities budgets.