Science and innovation: working towards a ten-year investment framework

Response from the UK Neutrino Factory collaboration

We welcome the invitation to provide input to the future investment framework for UK science solicited in the recent consultation document “Science and innovation: working towards a ten-year investment framework”\(^1\). The UK Neutrino Factory (UKNF) collaboration is making important contributions to the development of novel high-intensity neutrino sources that are internationally recognised. The worldwide consensus is that a Neutrino Factory – an intense high-energy neutrino source derived from the decay of a stored muon beam – is required to elucidate the properties of the neutrino (for background information see section 2 below). The worldwide consensus is that the Neutrino Factory is the only machine that can deliver neutrino beams of the quality and intensity that is required for the precision study of the neutrino. Since the Neutrino Factory science case is complementary to that of both the Large Hadron Collider and the Linear Collider, it is highly likely that such a machine will be built. The UK has world-leading expertise in the key technologies that will be required to realise the Neutrino Factory. This gives us a unique opportunity to lead the international design work, to provide substantial parts of the accelerator complex and indeed to bid to host the facility itself.

Section 1 addresses those of the questions posed in the consultation document that impinge directly on the likely success of the Neutrino Factory project. Background to the Neutrino Factory project is provided in section 2.

1. Responses to key questions posed in the consultation document

Q2: Which strengths of the UK science base could be further developed; what are the weaker areas that need to be addressed; and what are the risks to the UK’s continued production of internationally competitive levels of research? What criteria should the Government use to help determine its overall commitment to science?

The development of a capability in the provision of intense high-energy particle beams is of immense strategic importance. Particle beams are also of great importance in other branches of science such as nuclear physics, materials science, the transmutation of nuclear waste and in medicine. In the field of high-energy physics future developments will necessarily be of an inter-regional nature. The ISIS facility at the Rutherford Appleton Laboratory (RAL) in Oxfordshire is world leading in the production of spallation-neutrons and slow muons for research applications. To maintain and develop this lead requires sustained strategic investment in R&D into: acceleration systems including the provision of switched high-power RF sources; high-field superconducting magnets; the development of super-conductors and novel cryogenic systems and the development of solutions that take full account of the constraints imposed by the need to manufacture in bulk.

\(^1\) [http://www.hm-treasury.gov.uk/consultations_and_legislation/science_innov/consult_sciinnov_index.cfm](http://www.hm-treasury.gov.uk/consultations_and_legislation/science_innov/consult_sciinnov_index.cfm)
Q4: In order to inform decisions on the future investment framework, and building on the Research Council’s extensive consultations with stakeholders, in what areas are there opportunities for the UK research base to excel and contribute to the economy and society, which might form the basis of future strategic research programmes over the next ten years.

The Neutrino Factory facility has the potential to host first-rank science across a broad range of disciplines from biology and medicine to the investigation of the structure of matter at the most fundamental level and the symmetries of space and time itself. The UK is uniquely placed to seek to host the Neutrino Factory. The cost of the facility has been estimated to be approximately $2,000M. Were the machine to be sited here, the UK, as host, might be expected to contribute up to half. The international consortium that would necessarily be formed to implement the Neutrino Factory would contribute the rest. Clearly, such an activity would have a tremendous positive impact on industry both locally and across the UK. The international Muon Ionisation Cooling Experiment (MICE) is an inter-regional project with contributions from Europe, Japan, the US and the UK. MICE will be sited at RAL and will carry out a programme of measurement crucial to the success of the facility. The investment planned for the construction phase of MICE will already produce tangible benefits.

The opportunity that the Neutrino Factory represents for the UK has been widely recognised\(^2\). The facility could be built by the end of the next decade based on existing infrastructure in the UK\(^3\). The construction of such a facility will give rise to substantial opportunities both for the UK research base to excel and for enterprises of all sizes and types to develop capabilities and to win contracts. The cultural benefits that will accrue will be similarly substantial; not only will the facility be a cross-cutting hub for research but also the facility will attract large numbers of scientists of international reputation to the UK.

Q8: What is the optimal means of developing access to large research facilities at national and international level? How should funding of large facilities be prioritised?

The prioritisation of investment in large facilities must be based in large part on the breadth and scientific excellence of the research activities that the proposed facility will carry out. Clearly, the development of industrial capability and opportunities for wealth creation are also important factors. Lord Sainsbury, speaking at the dinner of the 4\(^{th}\) International Neutrino Factory workshop, NuFact’02, emphasised the strategic importance of strong UK involvement in international facilities and pointed out that the UK must achieve a balance in which it not only contributes strongly to large facilities overseas but also hosts first-rate, high-profile facilities itself\(^4\). The Neutrino Factory is an ideal candidate world-scale facility that the UK should seek to host. By so doing, we will ensure

\(^2\) The work of the Particle Physics and Astronomy Research Council’, HC 161.

\(^3\) Prof. I. Halliday, CERN Courier; Jan./Feb. 2004: [http://www.cerncourier.com/main/article/44/1/10/1](http://www.cerncourier.com/main/article/44/1/10/1)

that the UK is able to play a truly major role in the construction of the Neutrino Factory facility wherever it is built.

Q11: Do UK business leaders and managers have the necessary skills and knowledge to exploit new technology and research to maximum effect? Where are the areas of greatest weakness and opportunity in terms of sector size of enterprise and level of management? What can and should be done to bridge the gap?

Q13: What is the outlook for business investment in R&D over the next decade? How can business investment contribute to the success of a ten-year framework for science and innovation?

The next generation of accelerator facilities will make substantial demands on industry both in terms of innovation, for example in the provision of reliable high-power, switched RF systems and high-field, low-cost superconducting magnets, and in terms of the development of an appropriate manufacturing capability. The need to develop capability in the key areas has been recognised by the UKNF community, by CCLRC and PPARC, by the OST and by industry. The High Power RF (HPRF) Faraday Partnership now plays a key role in allowing those developing ideas and techniques for next-generation accelerator facilities and those enterprises that will supply equipment to work together. The partnerships being forged by the HPRF Faraday and others will lead to a mutual understanding of problems and the development of common solutions. Without a sustained commitment to the development of a capability in accelerator science the research base will not be able to deliver the competence and the capacity that the UK requires to be a leading player on the world stage nor will industry be able to realise its potential to win contracts for the provision of equipment to future large facilities.

Q20: Are there barriers facing business and the science base in effective engagement with EU research programmes? How can the UK more effectively influence and benefit from EU research funding and policies? In what ways can action at Community level add value to UK science and innovation policies? How can national and community funding complement each other more effectively?

The UKNF community is actively engaged with all regions in the development of the Neutrino Factory concept and in the essential hardware R&D programmes. We have successfully attracted funding for a Networking Activity ‘Beams for European Neutrino Experiments’ (BENE) under the Framework 6 Integrating Activities programme. BENE is part of the Integrating Activity ‘Coordinated Accelerator Research in Europe’ (CARE). The Networking Activity will allow us to take a leading role in planning the European contribution to the worldwide Neutrino Factory effort.

The world Neutrino Factory community is preparing to embark on a World Design Study (WDS), with the participation of Europe, Japan and the US. A first concrete step towards initiating the WDS was taken at the 5th Neutrino Factory workshop (NuFact’03). A steering group was set up that is composed of three people drawn from each of the three regions. With support from Europe and the
US, RAL is presently the most likely host laboratory for the WDS. To help fund the European contribution to the WDS it is planned to submit a proposal to the EU Framework 6 Design Study programme.

Coordination at a national, European and international level are requirements for the realisation of any future facility for particle physics. In Europe, The necessary mechanisms have been put in place by the European Committee for Future Accelerators (ECFA). The close interaction between those coordinating the Integrating-Activity (CARE) bid with the relevant members of the European Commission was a key component in the success of the bid. The UK, working closely with our European partners, must build upon this model if it is to be equally successful both in the forthcoming Design Studies bid and in future applications for EU funds.

2. The Neutrino Factory – background information

The Neutrino Factory is an intense high-energy neutrino source derived from the decay of a stored muon beam. The worldwide consensus is that only the Neutrino Factory can produce a sufficient neutrino intensity to allow the properties of the neutrino to be elucidated. Such a programme is of first importance because recent measurements imply that the theory of fundamental particles is incomplete. The implications of the discovery include the possibility that neutrinos are responsible for the removal of all antimatter from the early universe and that neutrinos play an important role in galaxy formation. The science case for the Neutrino Factory has been judged by peer review in the UK and across the world to be of fundamental importance. It is complementary to that of both the Large Hadron Collider and a future electron-positron Linear Collider and so it is highly likely that the Neutrino Factory will one day be built.

The Neutrino Factory complex will be a unique facility that has the potential to allow first-rate science across a broad range of disciplines to be carried out. For example: the high-intensity proton and hadron beams will be used for nuclear physics, the study of nuclear waste transmutation and the production of radio isotopes for use in medicine; the high-intensity muon beams will be used for materials science, particle physics and the development of novel radiotherapy techniques; the neutrino beams will be used to study the structure of the nucleon as well as being used to probe the properties of the neutrinos themselves. Each of these disciplines is an international endeavour; making the Neutrino Factory a highly attractive focus for international investment in basic science.

2.1 Opportunity for the UK

The crucial first stage of the Neutrino Factory accelerator complex is a very high power, low energy, proton beam. ISIS, the world’s highest current density proton accelerator, at RAL is an ideal candidate to form the basis on which the Neutrino Factory proton source is built. This, together with the world-leading expertise of the personnel in ISIS Division and ASTeC (the CCLRC Accelerator Science and Technology Centre) gives the UK the opportunity to play a unique role in the development of the Neutrino Factory and possibly also to host the facility.

With the strong support of PPARC and CCLRC the UKNF collaboration, are beginning to develop expertise in the key technologies upon which the Neutrino Factory relies. Work in the first
phase of the programme will concentrate on the development of accelerating structures for high-power, pulsed proton beams; studies of high-power particle-production targets; a cost-effective method of increasing the muon beam intensity; the development of the UK Neutrino Factory conceptual design; and the initiation and leadership of a worldwide Neutrino Factory design study. Our objective is to develop a complete conceptual design for the facility by the end of the decade backed up by a mature programme of prototype development and experimental measurement.

A crucial step in the production of the high-intensity muon beam at the Neutrino Factory is the phase-space compression, or cooling, of the muon beam using a technique called ionisation cooling. So far, this technique has not been demonstrated in principle or in practice. The Muon Ionisation Cooling Experiment (MICE) collaboration had been formed to take on this challenge. The work will be carried out by an international team of 150 physicists drawn from Europe, the US and Japan, using an existing experimental facility at RAL. MICE is the largest inter-regional collaboration working on Neutrino Factory R&D. It is therefore the focus of the attention of the Neutrino Factory community worldwide. To have attracted such an important and prestigious collaboration to the UK is immensely exciting. With strong moral and financial support from both PPARC and CCLRC, a committed and enthusiastic UK team has been established to carry it out.

2.2 Benefits to the UK

The cost of the Neutrino Factory has been estimated to be approximately $2,000M. Were the machine to be sited here, the UK, as host, might be expected to contribute up to half. The international consortium that would necessarily be formed to implement the Neutrino Factory would contribute the rest. Clearly, such an activity would have a tremendous positive impact on industry both locally and across the UK. The investment already planned for the construction phase of MICE will already produce tangible benefits.

In close collaboration with the Faraday Partnership in High Power RF Engineering (HPRF) UKNF seeks to maximise the possible industrial benefits that may accrue from MICE and the R&D phase of the UKNF project. Two areas are of particular importance are:

- High-power RF sources: While RF power at the multi-megawatt level and at the frequencies required for the Neutrino Factory is, for the time being, a rather unusual requirement outside the accelerator community, there is a growing interest in the possibility of using high-power RF energy in certain bulk industrial processes. These include oil-residue processing and the enhanced efficiency of rock comminution in the mining industry. Companies such as E2V Technologies, Chelmsford, Essex are directly involved in activities such as these and will be well placed to benefit from RF-systems developments that arise from the Neutrino Factory R&D programme;

- Super-conducting magnets: Each of the accelerators that make up the Neutrino Factory complex requires a large number of super-conducting magnets. These magnets will be

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developments of the type of magnets currently being built by, for example, Tesla Engineering Limited in Sussex or Space Cryomagnetics Limited in Oxfordshire.

Of course, there are also benefits that the development of such a capability represents in strengthening the UK’s technical and industrial position when bidding for ‘big science’ contracts that would go towards the UK’s contribution in kind.

2.3 Conclusion

Both CCLRC and PPARC have shown vision, breadth of view and a degree of confidence in the ingenuity, tenacity and strength of purpose of the MICE-UK and the UK Neutrino Factory collaborations by supporting MICE-UK and the initial phase of the Neutrino Factory R&D programme so strongly. The success of the MICE experiment in particular will position the UK at the forefront of research in this field. There is now a clear need for the science policy makers in government, CCLRC and PPARC to develop a strategy that will ensure that the UK science base, UK industry and the UK tax payer derive the best return. The UK must position itself to bid to provide substantial portions of the Neutrino Factory accelerator complex where ever it is built and indeed also to bid to host the facility. The imperative is to build and then to sustain the effort required to achieve this ambition.
3. The UK Neutrino Factory Collaboration

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