NUCLEAR PHYSICS PROGRAMME EVALUATION REPORT

EXECUTIVE SUMMARY

I. STFC supports three broad areas of activity in nuclear physics: Nuclear Structure and the structure of nuclear matter at the extremes of stability and angular momentum; Nuclear Astrophysics and the study of key nuclear reactions important for energy generation and nucleosynthesis in a variety of astrophysical sites; and Hadronic Physics and the nature of the strong force within hadrons and the phases of nuclear matter. These areas address some of STFC's top level science questions.

II. Since the nuclear physics community joined STFC in 2007 the number of academics has slowly increased, in part thanks to the support of STFC in creating a new Nuclear Physics theory activity at the University of York. Still it remains by far the smallest community in STFC's PPAN areas.

III. STFC currently supports three major international projects: the ALICE upgrade, ISOL-SRS construction and the Jefferson Laboratory (JLab) upgrade. UK academics have leadership positions in all three. In addition, STFC supports maintenance and operations for experiments at a number of international facilities such as ALICE, ISOLDE and MINIBALL at CERN and the ECT at Trento. The Panel discussed these projects and reasserted their importance to the future of the community.

IV. In line with the last Balance of Programmes review, the Nuclear Physics Grants Panel (NPGP) attempted, in its 2017 round, to reach the levels of support obtained by the community in 2011. This was only partially successful and came at a cost to the development budget with future project activity being traded for current exploitation. With the additional financial support to the exploitation line from the development line, the total number of PDRAs did approach the 2011 number but was still >5% lower and many could not be supported for the full grant period. In addition, academic time awarded averaged 9%, which is the lowest amongst the PPAN areas, and only limited support for the cross-community posts was possible. It was agreed that this transfer of funding from the development line was not sustainable in the medium/long term and would need to be redressed at the next Consolidated Grant (CG) point in 2021.

V. The Panel noted that the Cross Community (CC) team, which provides technical and engineering expertise to support the community, is extremely valuable. Much of the high reputation of the UK nuclear physics community internationally as a partner of choice is dependent on the technical capabilities of the CC staff, both in the design of new experimental detectors, facilities and systems and in the necessary operation and maintenance of current UK-led experimental systems that are used by a large number of international collaborations. The Panel noted that the balance of skills with the CC team may change over the next five years as new science opportunities emerge, requiring the adoption or development of new technologies. The skillset of the CC team should be monitored and a review mechanism should be built in the function of the CC team, feeding into the NPGP.

VI. As part of the Nuclear Physics Programme Evaluation (NPPE), the Panel considered 10 potential future projects. The Panel had sufficient information to rank (in priority order) three construction projects: AGATA, ACPA and DRACULA, and noted that they were all scientifically strong. Several other construction/upgrade projects were submitted but the Panel felt that as they only needed decisions in the medium term it was premature to consider them now.

VII. For the first time the community also submitted theory based projects. The Panel felt that while they both contained good science the PPRP assessment process, which is organised for major new projects such as the development of new instruments or upgrades to existing detectors, was not the appropriate route to consider them. The Panel encourages STFC to produce a more tailored mechanism for their assessment.

VIII. Given the situation faced by the NPGP in 2017 it is of little surprise that, looking forward in a flat cash or reduced funding scenario, the exploitation or development line (or both) will be damaged as support for the programme would remain critically low.

IX. In a flat cash scenario, reducing the exploitation line would significantly curtail the range of nuclear physics experiments that can be adequately supported. While a further period of reduced development funding would not only negatively impact on the future programme but also risk reputational damage to the UK.

X. In a -10% funding situation the Panel considered three scenarios that would protect either the exploitation line, the development line, or try to protect both which would require the UK withdrawing from the FAIR facility. In all cases the reduced support would seriously impact on the health of nuclear physics in the UK.

XI. In the slightly enhanced (+10%) funding scenario the uplift would help to restore the exploitation line to previous levels seen in 2011, partly mitigating the erosion of seven years of flat cash. Some support would also be given to the development line allowing the possibility of an additional project to be supported, such as enabling a theoretical nuclear physics project to be properly considered for the first time.

XII. The UK Nuclear Physics community has managed to maintain world leading status, as attested by it showing as being consistently 1st or 2nd in normalised citation indices [STFC Impact Report]. This performance is only possible with continued long-term support for PDRA positions to allow a pipeline of talent.

XIII. The UK community demonstrates significant leadership of the science agenda through roles as spokespeople on experimental proposals that are approved competitively by Programme Advisory committees at leading international laboratories, and through positions of leadership in large collaborations.

XIV. In summary, the 2017 CG round demonstrated that funding was already at a critical level. At that time decisions were made that if continued beyond the next grant assessment point would leave lasting damage on the community. If a flat or declining budget is expected then we would encourage STFC to form a specialist panel to consider in detail the actual budget available and its detailed implications for the programme. In the case of a slightly expanded budget the main outcomes would be to fully support PDRAs for the CG duration and give slightly stronger support to the development line.

XV. Conflicts of interest were dealt with by the Panel Chairs in accordance with STFC guidance. Panel members did not score or discuss projects with which they were conflicted.

1. Introduction

1.1. Atomic nuclei, consisting of protons and neutrons, make up 99.9% by mass of all visible matter. Despite being of femtometre scale, they influence matter across 26 orders of magnitude, right up to the largest known stars. The overarching goal of nuclear physics is to develop a detailed and predictive understanding of the fundamental properties of nuclei that can exist in nature and their interactions.

1.2. The UK nuclear physics community supported by STFC comprises 53 academics at 11 institutes, including STFC Daresbury. Approximately 75% of the STFC's Nuclear Physics Programme is funded through the exploitation line and 25% is funded through the development grants line.

1.3. The nuclear physics programme supported by STFC supports three broad areas: Nuclear Structure and the determination of the structure of nuclear matter at the extremes of stability and angular momentum; Nuclear Astrophysics and the study of key nuclear reactions important for energy generation and nucleosynthesis in a variety of astrophysical sites; and Hadronic Physics and the nature of the strong force within hadrons and the phases of nuclear matter.[1] Together, these three areas address several of STFC's top level science questions, including:

- What governs the structure and behaviour of atomic nuclei?
- What is the origin of the elements?
- What is the nature of nuclear matter?
- How do the properties of hadrons and the quark gluon plasma emerge from fundamental interactions?

1.4. The overall nuclear physics funding is £6.2M per annum, distributed as follows:

NP Programme	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26
Grants - committed	4.625	4.500	4.500	2.203				
Grants - uncommitted	0.300	0.300	0.200	2.402	4.605	4.605	4.605	4.605
Experiment support – committed (M&O)	0.150							

[1] Further information on the scope of the nuclear physics programme can be found in the Nuclear Physics Advisory Panel's Roadmap: https://stfc.ukri.org/files/uk-nuclear-physics-roadmap-2018-update/

Experiment support – uncommitted (M&O)		0.150	0.150	0.150	0.150	0.150	0.150	0.150
FAIR operations	0.050	0.175	0.275	0.370	0.370	0.370	0.370	0.370
NP development - committed	0.875	0.350						
NP development - uncommitted	0.125	0.650	1.000	1.000	1.000	1.000	1.000	1.000
Other - committed	0.020							
Other - uncommitted	0.055	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Total (Capital + Resource)	**6.200**	**6.200**	**6.200**	**6.200**	**6.200**	**6.200**	**6.200**	**6.200**

Financial forecast of the nuclear physics programme

1.5. The programme currently supports:

1.5.1. Exploitation:

- The current Consolidated Grant (CG) award is for £15.85M resource and £1.2M capital over a four year period from October 2017 to September 2021. The CG provides core support for the nuclear physics research programme to 11 institutes, including STFC Daresbury. The CG covers theory, the experimental programme and generic R&D. Cross Community (CC) effort is also supported on the CG.

1.5.2. Development:

- ALICE Upgrade Construction – Hadronic Physics, £2.7M support from January 2015 until December 2019. The ALICE-UK Collaboration plays a leading role in the ALICE upgrade programme at the LHC (CERN), with responsibilities for upgrading the Central Trigger Processor (CTP) and the Inner Tracking System (ITS).
- ISOL-SRS Construction, Installation and Commissioning – Nuclear Structure, £3.1M support from January 2015 until March 2019. To construct two spectrometers: an in-ring spectrometer for FAIR/CRYRING and an external spectrometer for CERN/ISOLDE.
- Jefferson Laboratory (JLab) Upgrade Construction, Installation and Commissioning – Hadronic Physics, £1.5M support from January 2015 until July 2018 to establish the UK in future programmes at JLab in the USA through major contributions to detectors and electronics of the SuperBigbite spectrometer in Hall A as well as to the forward tagger hodoscope in Hall B.

1.5.3. Other:

- Subscriptions and maintenance and operations for the experiments at international facilities such as ALICE, ISOLDE and MINIBALL at CERN, and the European Centre for Theoretical Studies in Nuclear Physics (ECT*) at Trento.

Leadership

1.6. Internationally the UK nuclear physics programme is world leading. From 2014 to 2016, in terms of highly cited papers, the UK is ahead of the other leading scientific nations in nuclear physics[2]. The UK nuclear physics programme aligns well with NuPECC (Europe) and NSAC (USA) long range plans, and the UK's leadership is reflected in the community's ability to win time on, and utilise, the world's best international facilities leading to scientific impact. In STFC's 2017 Consolidated Grants round, user support was requested for 28 international facilities, including ALICE, Argonne National Lab, GANIL, GSI/FAIR, CERN-ISOLDE, JLab, Jyvaskyla, RIKEN and TRIUMF.

1.7. The UK nuclear physics community has recognised international leadership and expertise. Such leadership is epitomised through the UK's involvement at international experimental facilities, where the UK is welcomed due to its leading science programme, theory leadership and expertise in the development of state-of-the-art instrumentation, for example germanium detector arrays and gamma-ray tracking, Monolithic Active Pixel Sensors (MAPS) and position sensitive scintillators.

1.8. UK leadership in nuclear astrophysics resides mostly at Edinburgh, Surrey and York, with several strong groups leading the measurement of nuclear structure and reaction properties of key nuclei of astrophysical interest. Edinburgh has leadership within the LUNA project and York has leadership within the UK BRIDGCE network. A section of the Surrey group is currently turning its focus to the study of nuclear reactions relevant for nuclear astrophysics and has a clear potential for leadership in the coming years. Both experimentalists and theorists are involved in the work at Surrey.

1.9. Experimental nuclear structure physics is a large component of the UK effort, led by the groups at Brighton, Birmingham, STFC Daresbury, Liverpool, Manchester, Surrey, West of Scotland and York. Its strength is based on historical leadership in gamma-ray spectroscopy, charged-particle spectroscopy and laser spectroscopy. Consequently the UK has a significant presence in most of the world's leading facilities, where often the leadership position has been driven by UK development of specialist spectroscopic equipment and techniques. This has led to strong leadership in research areas such as (for example): shell-structure & evolution using radioactive beams; reflection asymmetric nuclear shapes; shapes, radii, moments studied using laser spectroscopy; in-beam and decay spectroscopy of proton-rich nuclei; alpha-particle clustering in nuclei.

[2] STFC Impact Report 2017: https://stfc.ukri.org/files/stfc-impact-report-2017/

1.10. In all aspects of the UK experimental nuclear structure programme, detector hardware contributions and technical leadership during the early build phase or upgrade of experiments typically paves the way to scientific leadership during the exploitation phase. For example, the UK has designed and built key detectors for the HISPEC, DESPEC and R3B experiments at FAIR, been pivotal in the development of detection equipment for RITU/MARA at Jyvaskyla and for ISOLDE at CERN, and made leading contributions to the development of the AGATA detector. These developments maintain UK leadership in the study of exotic nuclei and of nuclei at the extremes of angular momentum and isospin. The UK has leadership at FAIR (NuSTAR board of representatives and experiment spokespersons) and leadership within AGATA (AGATA management board). At ISOLDE, there is UK representation on the ISOLDE Collaboration Committee, the MINIBALL Steering Committee and on the Group for the Upgrade of ISOLDE. The UK also active in the MINIBALL experimental programme (roughly 25-30% of experiments are UK-led). A highlight of this work was on octupole nuclei (Nature, 2013) led by Liverpool.

1.11. The UK hadronic physics community comprises groups at Glasgow and York (formerly Edinburgh) involved at experiments at JLab, and groups at Birmingham, Derby, Liverpool and STFC Daresbury involved in the ALICE experiment at the LHC. Glasgow and York have recently completed a project delivering detector upgrades to exploit the new 12 GeV electron beam at JLab. The upgraded detector systems are built around fast-timing scintillators that will enable the search for exotic hadronic states and extensions to the nucleon structure programme. Birmingham, Liverpool and STFC Daresbury are delivering a project to upgrade the ALICE experiment at the LHC. Birmingham is responsible for the upgrade of the trigger system and Liverpool and Daresbury for the construction of a significant part of a new silicon inner tracking system. These upgrades are essential for the future physics programme at ALICE, which focusses on rare particle probes, particularly heavy quarks.

1.12. In the hadronic physics community, scientific leadership stemming from detector hardware contributions can be demonstrated in various ways. At JLab, for example, UK nuclear physicists have been PI on more than 20 experimental proposals, have been elected Chair of the 200 member Hall B (CLAS) collaboration, serve on the JLab Programme Advisory Committee, and provide a co-PI on the future international KLong project. In the 1800 member ALICE collaboration, UK nuclear physicists sit on the Management, Technical and Upgrade Boards, provide Physics Work Group and sub-Group convenors and sit on the Editorial Board. UK groups therefore play a significant role in the scientific leadership of experiments at both JLab and CERN.

1.13. Leadership in UK theory comes in several forms; leading large international theoretical collaborations which require concerted multi-personnel effort, including computational support, such as the density-functional collaboration led by York, or the ab initio work led by Surrey. It also takes the form of being the principal go-to theoretician for experimentalists to approach for interpretation of new data, leading to many papers with UK nuclear theorists as main theory contributors to breakthrough experimental results. Recent examples include papers from TRIUMF, RIKEN and ISOLDE.

Synergies

1.14. Experimental nuclear structure synergetic connections are principally in the area of nuclear energy (EPSRC and industry). The nuclear industry benefits from UK nuclear academics leading technology training programmes. Examples are the Birmingham MSc in Physics and Technology of Nuclear Reactors, the NTEC consortium based at Manchester (MSc in Nuclear Science and Technology), the Liverpool MSc in Radiometrics and the Surrey MSc in Nuclear Science and Applications. A number of these have specific study modes designed for training current nuclear industry professionals. UK nuclear physicists are also leading the UK Nuclear Data Network which is concerned with nuclear data input required for reactors and nuclear site operations. There is a continued significant flow of trained nuclear physicists into the above areas.

1.15. Nuclear astrophysics has many synergies with nuclear structure physics which uses the same experimental facilities and many of the same techniques. Nuclear astrophysics is a key driver for the ELI-NP, ISOL-SRS (CERN/ISOLDE and GSI/CRYRING) and STAR projects. The multidisciplinary nature of nuclear astrophysics translates into strong collaborations between nuclear physicists, observational (ground-based and space-borne) astronomers, theoretical astrophysicists and cosmochemists.

1.16. Hadronic physics sits at the interface between low-energy nuclear physics and high-energy particle physics. Therefore, there is some natural synergy with the particle physics branch of PPAN. Looking to the future, there is potential common interest in a future electron-ion collider (EIC) in the United States, a successor to the former HERA electron-proton collider at DESY in Hamburg. The EIC will provide highly polarised beams of both electrons and protons, variable centre-of-mass energies and beam luminosities two-to-three orders of magnitude higher than HERA, driving developments in accelerator design. Several enabling accelerator technologies have been identified, including crab cavity operation, FFAG magnet design, beam energy recovery and interaction-region design, where UK accelerator expertise could make a decisive contribution to realising the facility.

1.17. Nuclear theorists working in the UK have direct collaborations and synergies with other science areas. Aside from their principal work in nuclear physics, synergies have led to publications by UK theorists in atomic physics, solid state many-body physics, quantum biology, astrophysics, field theory, computational physics and mathematical physics. These come about through shared theoretical or computational techniques, analogies between different physical systems and deliberate scientific collaboration with scientists from different fields. Direct industrial links are limited but recent work with AWE has called upon UK theory expertise to help interpret experimental work to better understand and extract nuclear data from surrogate reactions.

1.18. The European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) in Trento (Italy) provides a dedicated and structured combination of scientific activities for a large international scientific community. ECT* acts as an "intellectual" centre of competence, complementary in scope and activities to existing research facilities based at universities or experimental laboratories. It promotes coordination of European research efforts in nuclear physics and related research areas such as computational physics, particle physics and astrophysics.

1.19. The UK has been a member of ECT* since 2008. The annual running budget of ECT* in 2015 was 1.06M€. Nearly half (48%) of the budget is funded through the Fondazione Bruno Kessler. The next biggest contributors are France (11%), Germany (15%) and Italy (13%). The UK contribution was approximately 2.5% of the overall 2015 budget. Participation in ECT* provides excellent opportunities for building working collaborations whilst representing excellent value for money.

2. Breadth and Balance

Nuclear Structure, Hadronic Physics and Nuclear Astrophysics

	Percentage of Themes		**Percentage of PDRAs (by FTE)**		**Percentage of Academics (by FTE)**	
	2014	**2017**	**2014**	**2017**	**2014**	**2017**
Nuclear Structure	64%	66%	62%	54%	68%	61%
Nuclear Astrophysics	16%	14%	13%	14%	14%	16%
Hadronic Physics	20%	20%	25%	32%	18%	23%

Percentage of themes, PDRAs and academics supported on the CG per nuclear physics science area

2.1. The table above notes the balance of the programme supported through the CG in 2014-2018 and 2017-2021 across the subject areas.

2.2. While other nations are more diverse, the UK has focused on areas of strength. Though the UK nuclear physics community is smaller than France, Germany, Italy, Poland and Romania, it is more focussed on nuclear structure research, and here the effort is comparable with those countries.

2.3. The Panel considered that the balance between areas has developed over time and successfully built on leading expertise. It was felt that experiments are getting more complicated and that some areas may need to develop new expertise in order to maintain their world leading science. This process should be an evolution and not replace the areas in which the programme is successfully established.

2.4. Areas of nuclear physics can fall between the remits of EPSRC and STFC such as applied nuclear areas, detector development and nuclear data for the nuclear industry. Receiving support for these science areas can be challenging where clear funding routes are not obvious or difficult to access. This situation does offer the opportunity for greater interdisciplinary work and hopefully the creation of UKRI will ease cross-council working.

2.5. Within the UK nuclear physics community, 23% of academics focus their research within the area of hadronic physics. This has slightly increased since 2014, due to two hadronic projects being supported on the development line: ALICE Upgrade and JLab Upgrade. The field is complementary to both nuclear structure and nuclear astrophysics. UK hadronic physics groups have high visibility in experiments at the leading hadron-beam facility and the leading electron-beam facility in the world today. This reflects an optimal balance and breadth of the current scientific programme.

Theory and Experiment

	Percentage of Themes		**Percentage of PDRAs (by FTE)**		**Percentage of Academics (by FTE)**	
	2014	**2017**	**2014**	**2017**	**2014**	**2017**
Experiment	89%	83%	87%	82%	83%	75%
Theory	11%	17%	13%	18%	17%	25%

Percentage of themes, PDRAs and academics supported on the CG per theory and experiment areas

2.6. The nuclear theory community in the UK is small, but has increased in size since 2012, when it constituted 9% of total academic staff, to 14% today, thanks in part to STFC support for the new theory group at the University of York; the Panel congratulated STFC on this initiative. Following this, York appointed two academics to establish a new nuclear theory group for the benefit of the whole nuclear physics community. Since 2015 this new group has made a major impact in the field, revitalising UK leadership in this area, linking up with theorists at Surrey and Manchester, and enhancing connections with experimental programmes at other groups.

2.7. The areas of interest and expertise of the theory community are fairly wide covering nuclear density functional theory, effective field theory, reaction theory, hadron structure, ab-initio methods and applications to nuclear astrophysics. This rather broad range of areas for such a small community hides the gaps within the named topic areas and it was noted that compared to other leading nuclear physics nations, the UK nuclear theory community is relatively small. However, in order to tackle the most important scientific questions, it will be necessary to consolidate the UK leadership in these areas.

2.8. In common with any other area of nuclear physics in the UK, the nuclear theory area works with the major facilities around the world. In this case theorists make use of the results to test and refine theories and models, and to interpret the results in concert with experimental collaborators. Therefore, nuclear theory can be seen as playing a dual role of guiding and supporting experimental efforts and of developing and advancing new theoretical tools for the investigation of nuclei. As with the UK experimental community, collaboration with experimentalists is as likely to be around the world where the experiments are taking place than necessarily with other groups in the UK. The Science drivers are thus largely the same as those for the facilities themselves and the precision of data expected from new facilities will call for the use of ab-initio approaches and the exploitation of High Performance Computing (HPC). A challenge for the theory community, and the nuclear physics community as a whole, will be to grow the involvement with and support to the UK led experimental programme, which the Panel felt can be achieved most effectively with a continuation of the Nuclear.Theory.Vision@UK[3] initiatives aimed at providing TALENT (Training in Advanced Low Energy Nuclear Theory) courses, collaborative meetings, and a visitor programme.

Exploitation and Development

2.9. During the 2017 nuclear physics CG round the NPGP identified that maintaining the exploitation programme at flat cash would result in large reductions to academic support, core posts, cross community support and technical support. The NPGP noted that flat cash would cause lasting damage to the programme both in terms of science impact and capability. In particular a significant reduction in CC effort would lead to a direct loss in leadership and involvement in international experiments and would make support for future projects very difficult.

2.10. The Balance of Programmes (BOP) review made four recommendations for the nuclear physics programme, recommendations 8 - 11. In line with recommendations 8[4] and 9[5], STFC increased CG resource funding through redeploying resources within the

[3]http://personal.ph.surrey.ac.uk/~cb0023/uktheory/Nuclear_Theory_Vision_%40_UK/Nuclear_Theory_Vision_%40_UK.html

[4] **Recommendation 8**: We note that nuclear physics currently has a critically small level of support. For the 2017 grants round review in process, we recommend that additional funds be used to enable the restoration of fully-funded PDRA positions to the level of the 2011 grants round.

[5] **Recommendation 9**: We recommend that in any future scenario, the current NPGP grants line be funded at a level required to support the number of fully funded PDRA posts in the 2011 grants round. This aligns with the

approved flat cash nuclear physics programme. To do this, STFC used some nuclear physics development funding from 2019/20 to help offset the costs of the ALICE ITS Upgrade integration/commissioning and funds which became available due to delays in the FAIR facility construction.

2.11. The movement of funds from the development line to the exploitation line could not prevent a reduction in core posts, academic time and a lack of support for cross community posts on future projects. Science Board noted that some excellent research could not be funded and the programme was still very constrained. The risks associated with lack of support for CC posts, core posts and academic time were noted, including risks to some international commitments, future UK science leadership and maintaining core capability.

2.12. The NPPE agreed that the current balance between exploitation and development is correct for the funding envelope available. Moving funds to the exploitation line allowed the restoration of some CC effort to levels closer to the previous provision, thereby minimising the possibility of losing expertise and capability, and the corresponding loss of involvement and leadership in international experiments. The level of PDRA support should enable the community to maintain programme breadth. However, the Panel noted that not all PDRA posts were funded for the full duration of the grant. It was agreed by the NPGP that any reductions to the exploitation line would have a severely damaging effect on the science impact and breadth of the programme and in the size of the UK nuclear physics community, eventually leading to reputational damage.

Skills Balance and Pipeline

2.13. The table below shows the size and balance of the nuclear physics community supported through the CG.

community supported preference to maintain the consolidated grants at least at constant volume, at the expense of new project grants.

Consolidated Grants	2011	2014	2017
Academics – Awarded (requested)	46	52 (58)[6]	53 (65)[7]
Academics – Average FTE awarded	14.5%	11%	9%
Academics – Total FTE per year	6.3	5.6	4.5
PDRA – Awarded	29	21	27
PDRA – Total FTE per year	18.3	16.1	18.2
Ratio PDRAs to Academics	0.42	0.31	0.34
Core Posts – Awarded	11	12	9
Core Posts – Total FTE per year	8.3	7.9	6.8
Cross Community - Awarded	13	14	16
Cross Community - Total FTE per year	12.1	10.3[8]	11.3
Number of Studentships	2	1	3
Technician – Total FTE per year	-	2.1	2.9
Total Number of FTE per year	47[9]	43	46.7

Size of the nuclear physics community supported on the CG

2.14. The table above shows that the number of academics awarded FTE on the CG in 2017 is approximately the same as in 2014 and has increased from the 2011 level. However, the average academic time awarded has decreased from 2011 and 2014, and is now at 9%, the lowest of the PPAN programmes.

2.15. The number of PDRAs awarded has increased from 2014 and is now in line with 2011 levels, as per the BOP recommendation. However, comparing the ratios of PDRA FTE to funded academics against the PPAN programmes, the ratio for nuclear physics is higher than PPT but lower than PPE and astronomy (see table below). The Panel agreed that PDRAs have reached a level too low to properly support the programme. Whilst the number of PDRAs was almost restored to the 2011 level, the duration of

[6] Does not include three emeritus posts

[7] Does not include six emeritus posts and 1 Royal Society Fellow

[8] An additional 6.4 FTE of cross-community effort was supported through the ALICE Upgrade and ISOL-SRS projects. The previously funded baseline level of cross-community effort is approximately 12 FTE per year.

[9] Does not include Technician effort

support given to PDRAs was reduced from 48 months to 24 or 36 months. This risks the programme losing long-term expertise and deterring new talent. Furthermore, to restore the levels of PDRA effort, funding was reallocated from the projects line, thus negatively impacting the project line which may have long term consequences in terms of UK skills, knowledge and leadership.

2.16. Support for PDRAs is critical in delivering the research programme and maintaining the UK's internationally leading position and science impact. The mobility of PDRAs ensures that the UK can join and participate in international facilities and collaborations, maintaining the UK's reputation for being good collaborators. PDRAs also play an important role in responding to new research areas and driving leadership in such areas. Therefore, additional support for PDRAs would allow the breadth of the UK nuclear physics programme to grow whilst ensuring that the quality of the existing programme is maintained.

2.17. The Panel re-affirmed that support for the whole programme remains at a critically low level. To maximise the available support for PDRAs and CC staff, whilst meeting the available budget, the NPGP could not avoid reducing academic FTE and core support. The current level of support for the nuclear physics programme risks the community not being able to maintain programme breadth and the range of world-leading research it performs.

Grants Round	**Ratio PDRAs to Funded Academics**	**Ratio PDRAs to Requested Academics**
Nuclear Physics 2011	0.42	0.35
Nuclear Physics 2014	0.31	0.27
Nuclear Physics 2017	0.34	0.28
Particle Physics Experiment 2012	0.37	0.34
Particle Physics Experiment 2015	0.38	0.36
Astronomy 2014	0.55	0.25
Astronomy 2015	0.46	0.17
Astronomy 2016	0.58	0.25
Particle Physics Theory 2013	0.20	0.19
Particle Physics Theory 2016	0.27	0.20

Ratio of PDRAs to academics for STFC Programmes

2.18. The broad ratio of the size of the community relative to that of particle physics and astronomy is 1:4:6, respectively. The Panel noted that the low level of academic time paid by STFC is already a concern to some Vice Chancellors who are questioning the cost of nuclear physics. This risks universities not replacing posts as well as not creating new posts, thereby moving support from nuclear physics to other areas. This may disproportionately impact some groups more than others as academic FEC is managed and perceived differently by different universities.

2.19. The Panel agreed that the gender balance within the exploitation and development lines was poor. Within the exploitation line 16% of PIs and Co-Is supported are female and only 9% of PIs and Co-Is supported on the development line are female. From their experience, the Panel believed that the balance of female to male PhD students within nuclear physics had improved over the last decade and will eventually transfer into an improved balance between male and female academics. The Panel also noted the importance of positive and visible role models, both male and female, to encourage young students into STEM education and agreed that the nuclear physics community was extremely proactive in such outreach activities as noted in Section 3.

2.20. It was noted that there is a general consensus in the community that UK leadership in a number of key technical areas is at risk in the longer term. This includes mechanical design, electronic engineers and detector specialists. There is an ongoing shortage of skilled technical effort to provide professional support across the breadth of the nuclear physics programme for both the development and exploitation programme. Failure to adequately support these posts will ultimately erode the UK's ability to maintain areas of established technical leadership. At an institutional level, this has resulted in a significant reduction in the level of technical support and an increasing reliance on the goodwill of universities to maintain an appropriate level of technical effort.

Skills pipeline

2.21. Nuclear physicists are frequently invited to share their knowledge and talk about their research at schools, science festivals and community groups. Over 1000 students, teachers and members of the public are engaged through these activities each year. The community also runs nuclear physics continuing professional development workshops for teachers and masterclasses for students. Such workshops and masterclasses help to improve teaching at GCSE and A-level and encourage young students into nuclear physics and STEM education.

2.22. STFC's Ernest Rutherford Fellowship scheme is well-received by the community and plays an important role in enabling early career researchers to obtain permanent academic appointments. However, support for more junior fellowships is also required, such as the previous Postdoctoral Fellowships, to aid the pipeline of staff to enable new talent to grow, and to help mitigate the low number of PDRAs.

2.23. There are skills development opportunities within nuclear physics which do not exist in other fields which rely on large central facilities. For example, a nuclear physics experiment often offers a PhD student the opportunity to design and build the setup, tune the electronics and DAQ, perform the data analysis and interpret the results. This enables researchers to be well trained and highly skilled. In addition, all research groups offer PhD training in nuclear physics which provides a steady stream of highly trained nuclear physicists for future research, academic leaders, as well as for industry.

2.24. In the revitalisation of the nuclear industry, Birmingham, Liverpool, Manchester and Surrey have grown their research and educational programmes to include nuclear industrial training for MSc students and Continual Professional Development. These strongly link technology development in instrumentation, materials, chemistry, geology and biosciences and as such have significant potential for the development of applied science across the disciplines.

2.25. In collaboration with the Royal Liverpool University Hospital, the University of Liverpool and STFC Daresbury have established the Medical Training and Research Laboratory (MTRL). MTRL provides hands-on training in medical imaging and develops next generation imaging techniques. The MTRL houses a SPECT/CT scanner that allows students to receive a first-class training experience away from the daily pressures of the hospital environment, where there is often a long wait for access to such in-demand scanning equipment. The facility also allows researchers to test new imaging algorithms and instrumentation systems that are designed to be more efficient and of higher quality for medical diagnosis.

Cross-Community Team

2.26. The CC team provides the technical and engineering expertise essential to the design, development, installation and ongoing support of state-of-the-art detector systems operating at nuclear physics laboratories worldwide. Consisting of mechanical, electronics, and software engineers, and a target technician, CC personnel provide expertise in key areas of nuclear physics and are available to provide support to the whole community. The CC team is principally funded through the exploitation line with some funding coming from the development line. Some recent examples of their activities include:

2.26.1. A major role in the detector development for the NuSTAR project where the mechanical engineers developed the mechanical structure and cooling system for the LYCCA electronics, part of the HISPEC detector. This was installed and commissioned at Cologne ready for testing and experiments prior to its eventual deployment at the FAIR facility. The electronics engineers were involved in the construction of the R3B silicon tracker for NuSTAR at FAIR including the development of the silicon ladders, buffer boards and readout system for the ASICs.

The components are undergoing final system testing in advance of shipping to GSI in 2018 and are essential components for the NuSTAR project.

2.26.2. Software engineers have pioneered techniques to handle data from the mixed detector and data acquisition systems typically used in nuclear physics experiment setups. A particular achievement was the realisation of the total data readout system implemented for the GREAT spectrometer, which has now been copied in many international projects and is becoming a global standard.

2.27. In 2016, following discussions with the nuclear physics theory community, STFC agreed to extend the principle of CC effort to include core theory posts which would provide support to the wider nuclear physics experiment programme. It was agreed that the NPGP would consider and prioritise requests for CC theory support as part of the CG round. However, given the restricted funding available, and there being higher priority posts, the NPGP was unable to award support for new proposed CC theory posts.

2.28. The key challenges to the CC team are the funding, recruitment and retention of staff. Overall, nuclear physics funding from STFC is constrained and the team is tensioned against the wider funding of nuclear physics, for example PDRAs. Tensioning against the programme risks losing the breadth, depth and balance of technical and engineering capabilities and hindering the acquisition of new skills and knowledge for future projects.

2.29. The Panel noted that the CC team are very valuable to the nuclear physics community. Much of the high reputation of the UK nuclear physics community internationally as a partner of choice is dependent on the technical capabilities of the CC staff, both in the design of new experimental detectors, facilities and systems and in the necessary operation and maintenance of current UK-led experimental systems that are used by a large number of international collaborations. Furthermore, it was considered that a continuing flow of new projects is important for the CC team as it provides exciting technical challenges and the opportunity to develop and exploit new technologies and acquire new capabilities to the benefit of the UK science programme. It also helps to attract high calibre applicants with new skills and expand the knowledge base.

2.30. In order to monitor and manage the resource allocation of CC effort, STFC set-up a Cross Community Committee (CCC). The CCC is tasked with: reviewing requests for CC effort prior to the submission of grant applications to STFC, providing input to the NPGP, monitoring the usage of CC effort, and to discuss succession planning.

2.31. The Panel noted that the balance of skills within the CC team will need to adapt over the next five years as new science opportunities emerge, requiring the adoption or development of new technologies. It should be ensured that the skillset of the CC team meet the emerging needs of the community. The skillset of the CC team should be monitored and the mechanism for appointing new members should be reviewed. Building a review mechanism into the function of the CCC will ensure the use of CC effort is maximised for future CG rounds and projects. Consideration was also given to broadening the skills and scope of the team to other areas, such as computing.

Recommendation I: Reviewing the future needs of the community, in terms of skills, breadth, balance and level of cross community effort, should be embedded into the function of the Cross Community Committee, feeding into the NPGP. This will enable the cross community team to be proactive in supporting new and growing areas of the UK nuclear physics programme.

3. Societal and Economic Impact

3.1. Despite the small size of the community, UK nuclear physics has a long legacy of societal benefits. Accelerator technology that was developed to study nuclear phenomena is now being used in proton beam cancer therapy and many of the detection systems used for medical imaging, such as SPECT and PET, originated in nuclear physics research. In addition, nuclear academics at Liverpool lead one of only three national Modernising Scientific Careers (MSC) Medical Physics MSc courses, funded by the NHS.

3.2. Societal impact examples include the nuclear physics masterclasses aimed at A-level students (which have been led by all institutions involved in nuclear structure research) including schemes such as Headstart, Smallpiece Trust and Teach the Teachers. The Binding Blocks (Lego-based) activity is a highly-regarded nationally organised activity aimed at school children and there are many other events, public lectures, residential courses that are led by the UK nuclear physics community.

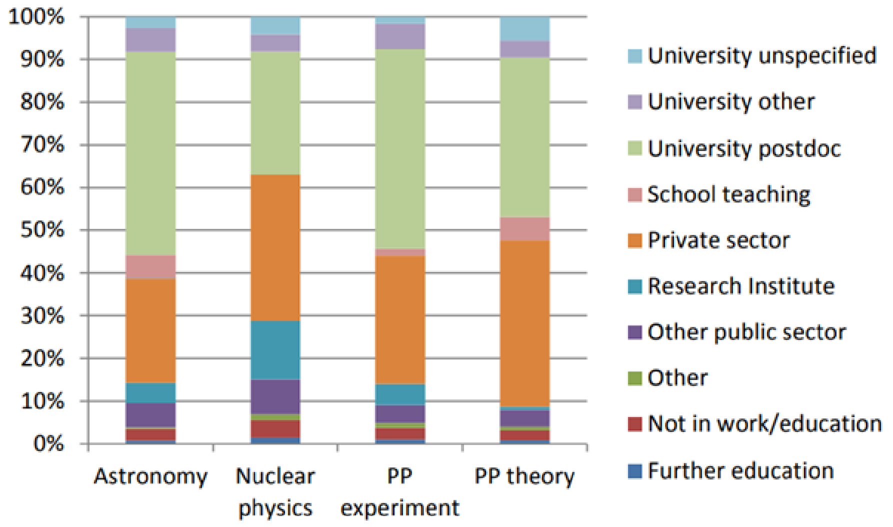
3.3. The community continues to have a very productive collaboration with industry and the majority of UK universities have significant industrial engagement programmes which support knowledge exchange and the development of future REF returnable impact cases. For example, the University of York have developed a hand-held gamma-ray detector based on an SiPM array for Kromek[10]. The detector led to a product called SIGMA sold by Kromek and is now part of a device called D3 which is intended to be worn by the law enforcement community. This work was followed up by a mini-IPS project to further develop the SIGMA probe.

3.4. There is significant technology impact in industry, nuclear medicine and homeland security that has come out of UK detector-based research and from the advanced modelling and simulation techniques developed. For example, Birmingham holds a US Department of Energy funded grant to explore silicon MAPS technologies for a future EIC

[10] https://www.kromek.com/

experiment. MAPS are widely regarded as the technology of choice for future high-granularity silicon tracking systems (e.g. at the HL-LHC), digital (particle flow) calorimetry and they have potential applications to healthcare (e.g. dosimetry for proton therapy exemplified by the PRaVDA project).

3.5. Students and fellows studying nuclear physics are highly desirable to employers due to their experience of problem solving, working in large projects and international collaborations. Nuclear physics students and fellows often have strong communication and presentation skills; they have important international experience, additional language skills, financial and project skills, and are team players whilst being able to work independently to solve complex problems. First destination data of PhD graduates in astronomy, nuclear physics, particle physics experiment and particle physics theory from 2012 – 2015 is provided below. The bar chart shows that nuclear physics has the second highest percentage of PhD graduates going into the private sector, with approximately 12% working at a research institute, highlighting the attractiveness of UK PhD graduates.



First destination data of PhD graduates in astronomy, nuclear physics, particle physics experiment and particle physics theory from 2012 – 2015

4. Future Programme

4.1. As part of the NPPE, the Panel was required to assess, score and rank current and future projects. 13 projects were received, three of these were projects that were ongoing (JLab, ALICE and ISOL-SRS), three projects had submitted Statements of Interest (SOI) with project start dates in 2019 (AGATA, ACPA and DRACULA), five projects have start dates beyond 2019 and two nuclear theory projects with project start dates in 2019 (Neutrino Nucleus and Fission). The ranking criteria can be seen in annex 1.

4.2. The Panel agreed that exploitation of ALICE, JLab and ISOL-SRS were of equal priority. The Panel agreed that these projects were of high strategic importance in the STFC programme and they have received substantial investment. The Panel would expect to see their exploitation adequately funded through the CG to ensure a return on past investment. In addition, the Panel agreed that ALICE and ISOL-SRS have good impact and societal engagement potential as they move towards exploitation and agreed that the impact of JLab was very exciting with good progress already made. All three projects were viewed as G3 for Exploitation. JLab was ranked as I5 for Impact and Engagement, whilst ALICE and ISOL-SRS were ranked as I3.

4.3. Of those projects that had submitted SOIs, the Panel identified the AGATA Upgrade as the most scientifically excellent and the highest priority. The Panel agreed that AGATA was likely to substantially advance the subject, with very exciting industrial impact and engagement with non-academic partners already in place. The Panel agreed that not supporting the AGATA Upgrade, where the UK has played a leading role in its development and exploitation, would result in reputational damage to the UK. AGATA was ranked as A4 for Scientific Excellence and I5 for Impact and Engagement.

4.4. ACPA was ranked second to the AGATA upgrade project. The Panel noted that while the project had high potential for excellent science and was likely to advance the subject, it was unclear what the timescales of ACPA and the availability of gamma beams at ELI-NP were. However, the Panel acknowledged that the project would benefit a wider community creating the potential for interdisciplinary and multidisciplinary science. ACPA was scored as A3 for Scientific Excellence and I4 for Impact and Engagement.

4.5. Of the three projects that had submitted SOIs, DRACULA was ranked behind the AGATA Upgrade and ACPA. The Panel considered that the project would advance the subject but considered that the work proposed did not represent good value for money. Furthermore, the Panel considered that while interesting opportunities for industrial and societal engagement were proposed, work was required to develop these ideas further. DRACULA was ranked as A3 for Scientific Excellence and I3 for Impact and Engagement.

4.6. The Neutrino-Nucleus project, which concerns the development of state of the art theoretical techniques to study neutrino-nucleus physics, and the Fission project, which aims to revolutionise the description of nuclear fission, were reviewed by the Panel. The Panel agreed that the Neutrino-Nucleus project was scientifically excellent, likely to substantially advance the subject and could lead to the UK becoming international leaders. The Panel ranked the Neutrino-Nucleus project A4 for Scientific Excellence, above the Fission project which was ranked as A2. The Panel was unsure if the activities proposed in the Fission pro forma were sufficiently different from those activities currently supported on the CG and agreed that the project was not of the highest strategic importance to the UK.

4.7. While nuclear theory projects, such as the Neutrino-Nucleus and Fission projects, are not excluded from submitting an SOI, it was felt that the PPRP assessment criteria are not well matched to projects of this nature and that STFC should consider a more tailored mechanism to ensure future nuclear theory projects that are scientifically excellent and of strategic importance, have a route to apply for funding outside of the CG to give sustainability and strategic direction that can help to deliver science impact.

4.8. The Panel considered five projects that had not yet submitted an SOI to Science Board but had start dates beyond 2019. These were EIC R&D, STA@RIKEN, Jyväskylä Upgrade, NuSTAR 2 and JLab Upgrade 2. These medium term projects are very promising and have the potential to address many of STFC's scientific questions. The Panel considered that the projects were in their very early stages and prioritising them within this review would be premature, considering that the science landscape may change.

Project Research and Development

4.9. The Evaluation Panel noted that the suspension of the Project Research and Development (PRD) scheme, which aimed to develop the capabilities needed to underpin UK science and technology leadership in future STFC projects, was a blow to innovation in the field

4.10. The panel noted the need to have a call for key development projects that can lead into future projects. There will be a review of the PRD scheme in 2018/19. The panel agreed that any future PRD scheme should not be used to support or topup any lowly funded or unfunded areas on a consolidated grant or project grant. The panel believes that the PRD call is of great value and should be reinstated.

Recommendation II: The Panel welcomed the planned review of the PRD scheme and agreed that STFC should reinstate the PRD scheme and that it should be targeted at demonstration-level technology development.

Facilities

4.11. The UK community has a significant presence in the world's leading nuclear physics facilities, where often the leadership position has been driven by UK development of specialist spectroscopic equipment and techniques. At some facilities the UK presence is large and UK-led science is a significant component of the facility's programme, for example at the University of Jyväskylä (JYFL), ISOLDE and GSI/NuSTAR. Between 2006-2017, 36% of the proposals at JYFL had a UK spokesperson and, in the recent

Jurogam III and MARA beam-time allocations at JYFL, over 60% were UK-led proposals.

4.12. The UK is positioning itself well in relation to the major facilities being built in Europe and USA, for example SPES (Italy), FAIR (Germany), ELI-NP (Romania) and FRIB (USA). This is evidenced by advanced plans for science exploitation and the planned new projects (AGATA, ACPA and DRACULA) intended for these facilities. The nuclear physics community carries out experimental work in many different labs; the strategy being to select the facility that best matches the scientific goals of a measurement. This has been the modus operandi of the UK nuclear physics community for at least twenty years.

4.13. The Panel noted that the UK does not have its own national facility and is therefore reliant on international facilities for both future development activities as well as for exploitation. A small-scale UK nuclear physics facility, where the UK has control of its strategic direction, would significantly enhance the UK's status and help the UK to deliver societal and economic impact, skills development and knowledge transfer. Such a facility would have applications to medical physics and nuclear energy as well as nuclear physics, illustrated by the use of the MC40 cyclotron at Birmingham for example, and would allow the development of new ideas and experimental techniques that could subsequently be exploited at major international facilities.

4.14. Full operation of the Facility for Antiproton and Ion Research (FAIR) at Darmstadt, Germany is scheduled to start in 2025. It will be a new international accelerator facility for research with antiprotons and ions. The UK (STFC) joined FAIR as an Associate Partner in 2013. As an Associate Partner, the UK is not a full shareholder and is not legally liable to contribute to the construction of the facility. The "Facility for Antiproton and Ion Research – FAIR" will be built near the premises of the renowned physics research institute GSI Helmholtzzentrum fur Schwerionenforschung. UK commitments are currently limited to the experimental programme where STFC is contributing €5M (Cost Book value) in both cash and in kind. This has been delivered primarily as part of the international NuSTAR Collaboration but also includes a contribution to the APPA programme, which leverages investment in the ISOLDE experiment at CERN. The UK-STFC is also committed to contribute to operations costs for the FAIR facility with a minimum of 0.5% of the annual operating costs, once the operation of the FAIR facility starts.

4.15. The FAIR-STFC Associate Partner agreement is limited and only remains valid until three years after the beginning of the operation of FAIR. After this period, STFC's status may be negotiated and any future international subscription to FAIR will be subject to further negotiation on UK membership and whether we become a full member. The planning assumption is that, as for other international organisations (e.g. CERN, ESO, ESRF), facility operations would be funded as a UK international subscription and would not be a call on the nuclear physics programme. However, costs associated with the experimental programme to maintain and operate UK instrumentation will come from the exploitation line of the nuclear physics programme. These costs are not yet known, but by 2021, as the FAIR Phase 0 experimental programme ramps up, it is anticipated that these M&O costs could be up to £400k p.a.

4.16. The community believes there are many benefits from UK participation at FAIR. The nuclear structure physics and nuclear astrophysics communities feel that even though the scope of FAIR has changed slightly, partially due to delays, a good return from the UK's contributions/deliverables has already been achieved due to the instrumentation developed for the (delayed) FAIR experimental programme being utilised at other facilities. It is felt that for a small investment the UK could gain an excellent return from FAIR, in terms of science, collaboration and expertise.

4.17. The panel agreed it was too early to decide whether the UK should become a full member of FAIR. A recent survey conducted by the Nuclear Physics Advisory Panel (NPAP) showed that the nuclear physics community remains supportive of the UK's engagement with FAIR. The panel considered there is a natural point to review the UK's membership to FAIR prior to the end of the first three years of full operation. At this point it would be appropriate for STFC to conduct a review of the UK's membership to FAIR.

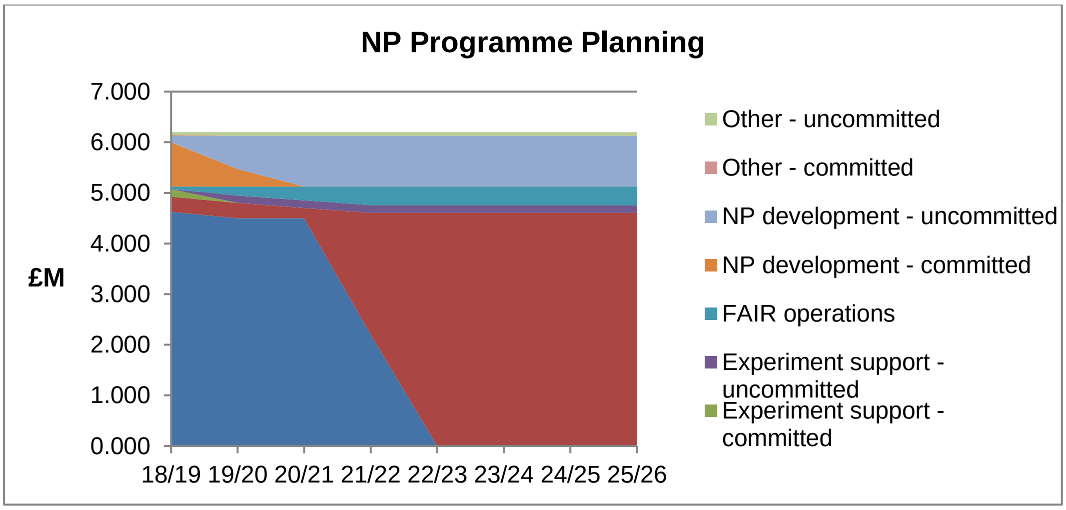
Recommendation III: STFC should review the UK's membership to FAIR prior to the end of the first three years of FAIR operation. At this point it will be timely to obtain the views of the nuclear physics community with regards to the benefits and return of the UK's participation in FAIR.

Computing Needs

4.18. The Panel noted that the nuclear physics theory community relies heavily on computing and has successfully gained time on DiRAC. The variety of research interests within nuclear physics theory is healthy and benefits from novel ideas and from advances in high performance computing (HPC). Major new initiatives within theory and experimental nuclear physics will only be possible if access to HPC is available.

4.19. In the future, the need for computing, data handling and data storage from experiments will increase beyond current capabilities. Data storage will need to be addressed by not only the nuclear physics community but the science community as a whole. In addition, the Panel agreed that the computing demand will increase greatly over the next generation of experiments. For example FAIR, which doesn't currently have a complete computing model, will almost certainly need to start ramping up its experimental programme from 2021

5. Financial Planning Scenarios



Financial forecast of the nuclear physics programme

5.1. Under a flat cash scenario, the Panel agreed it is imperative that there is no reduction in support for exploitation, and agreed that the short term movement of development funds to exploitation is not sustainable and demonstrates how the lack of core funding is now at a critical level. This critical level of support is negatively impacting on future projects and threatens reputational damage to the UK. However, a reduction to the exploitation line would significantly curtail the range of nuclear physics experiments which can be adequately supported, increasing the risk to the nuclear physics experiment and development programmes, both in the short-term and, more importantly, the longer-term. Therefore, the Panel agreed that the current funding level of the CG should be maintained into the next CG round. This would result in reducing the development line to £700k (dependant of FAIR contributions) but would roughly maintain PDRA support. A development line of £700k would only allow STFC to support one of the three experimental projects considered by the Evaluation Panel, potentially deferring a second.

5.2. In a -10% situation, the Panel explored three possible scenarios;

5.2.1. Scenario A - The exploitation line would be protected from the reduction. Therefore, the development line would be reduced by approximately £600k. Therefore, a 10% reduced funding scenario would leave only £100k within the development line, essentially preventing involvement in any future project. This problem would be magnified as it has to be assumed that FAIR operating costs will rise. This scenario would protect the exploitation line, allowing the UK nuclear physics community to exploit the UK's past investments, such as the UK's contribution to the ALICE Upgrade. However, the scenario risks eliminating potential leadership in future projects and would prevent the UK from building on skills and expertise in areas such as detector development. It also carries serious reputational risk regarding the reliability of UK contributions to international projects. The lack of future projects would also lead to a lack of work for the CC team and could lead to skilled scientists permanently leaving the UK or the discipline.

5.2.2. Scenario B – The development line would be protected from the reduction. In this scenario, there are several options for making cuts in the exploitation line: further reductions to PDRAs and CC posts would have an extremely damaging effect on top priority and high priority themes; alternatively, if the top and high priority themes were protected it would lead to a loss of significant research volume. As an example in the current CG, a £600k reduction could see the loss of 10 out of 16 prioritised themes. These options would need detailed consideration to minimise reputational damage and loss of leadership, and avoid a poor return from investment. For example, cutting themes according to their ranking would have resulted in the loss of the commissioning and integration activities connected to part of the UK's contribution toward the ALICE Upgrade, meaning that the UK would not have been able to participate in the wider commissioning and integration of the ITS according to the expected fair share agreement. It would have also removed all funding support for one UK university group.

5.2.3. Scenario C – Withdrawal from FAIR to protect both the development line and exploitation line. From 2021, it is anticipated that experiment M&O costs will be up to £400k per annum. This would absorb 66% of the 10% reduction with the remaining 33% coming from the development line, leaving £500k for a reduced project. Withdrawing from FAIR at this point would minimise reputational damage, but would result in the UK missing out on world leading science and leadership in the science area.

5.3. A 10% increase in the nuclear physics programme would allow PDRAs awarded on the CG to be supported in full providing meaningful support to priority themes. Providing additional staff resources would broaden the range of supported physics and secure an increase in world-class physics from the Programme. Supporting those PDRAs in full on the CG would cost approximately £200k, the remaining £400k should be used to restore the development line allowing an additional project to be supported. The 10% increase would restore the nuclear physics programme to previous levels seen in 2011 and would help to reverse the erosion of flat cash.

UKRI Directed Funding

5.4. The creation of UK Research and Innovation (UKRI) in April 2018 has coincided with overall Government funding for research and innovation seeing a significant uplift. The panel noted that new investment is being made through a number of new directed mode funds, with STFC (and other RC) allocations currently being held to flat-cash, which required a different approach to future planning. These new UKRI funding schemes included the Strategic Priorities Fund, Fund for International Collaboration and Strength in Places Fund.

5.5. These funds are open to the UK science community and aim, in part, to drive an increase in high quality multidisciplinary research and innovation and build collaborations nationally and internationally. Fundamental research needs to be supported at a sustainable level to ensure a pipeline into technology development and impact. It was agreed that in the current funding climate, accessing such funds could significantly relieve some of the financial pressures elsewhere within the nuclear physics programme. Four outline nuclear physics proposals had recently been submitted to STFC as part of the STFC Priority Project - Delivering a World Class Research Programme - initiative to exploit these modes of funding.

5.6. The Panel agreed that while these new funding modes present a significant opportunity to the programme, such funds are not a replacement for core funding which underpins the programme. The Panel was concerned at the reliability of gaining support through such schemes, for which the competition would be high. Furthermore, the Panel agreed that science areas, such as nuclear theory, may find it difficult to meet the requirements of future schemes, and may result in third-rate science being supported over areas that have UK leadership. However, the Panel welcomed the opportunity to gain additional support and noted that the community should consider how collaborations can be formed both within and outside of the nuclear physics community, and with industrial partners, to manoeuvre university groups or consortia into a position to submit proposals for future calls arising from UKRI.

<u>GCRF and ISCF</u>

5.7. The emergence of the Industrial Strategy Challenge Fund (ISCF) and the Global Challenge Research Fund (GCRF) creates an opportunity for nuclear physics to receive additional financial support; and the nuclear physics community should consider how to access these major funding schemes. In 2017, four proposals were received in the area of nuclear physics for the GCRF Foundation award. The applications from the discipline had a 50% success rate. The community has welcomed the new pump priming activities, such as the recent Opportunities Call, and agree that more action is required in order to capitalise on new funding streams that could help to release financial constraints within the programme.

5.8. In 2017, the GCRF supported a workshop on Advanced Nuclear Science and Technology Techniques (ANSTT) at iThemba LABS, Cape Town, to build capacity and collaboration between UK and African scientists. Work resulting from this workshop may lead to future opportunities in both applied research and training. In addition, opportunities also exist with similar workshops in different science areas or other developing countries.

5.9. There are opportunities for the UK nuclear physics community to work with the International Atomic Energy Authority (IAEA). The IAEA is contributing to the achievement of the UN Sustainable Development Goals by helping countries to use nuclear and isotopic techniques to address areas such as hunger, health and well-being, water and sanitation, energy, industry and climate change. The community has key capability in nuclear education, training and research and has strong relationships with the IAEA, which could have potential for GCRF research and training.

5.10. In 2017, STFC provided funding for 20 students from ODA countries to attend the CERN Summer Student Programme. The aim of this was to give the students exposure to the very latest physics, computing and engineering enhancing their knowledge and skills. It is anticipated that sharing the knowledge and contacts with their home institute will provide an opportunity to enhance STEM skills. The Evaluation Panel noted that similar initiatives could be used at FAIR or other international facilities. Such support through GCRF would help to develop skill sets within developing countries and create international collaborations.

5.11. One potential route to the ISCF could be through Centres for Doctoral Training (CDTs) that involve industrial collaboration. Nuclear physics involvement in CDTs with industrial partners could lead to innovation in areas of detector development and SiPM technology, as well as the capability of collaborative research both nationally and internationally.

European Grant Income

5.12. Currently, European grant income for the UK nuclear physics community is 23% of the grant income received from STFC, compared to 41% in Astronomy and 20% in Particle Physics. Post 2020 the UK must ensure that either access to this funding is maintained or that the funding is replaced in full to maintain the breadth and balance of the programme.

5.13. The Panel was concerned about the possible implications of BREXIT and noted that the issue of flat cash in the UK programme would make it more difficult for the UK community to manage any detrimental impacts. In addition to the potential loss of EU funding the UK programme has a high level of international interactions both through the attractiveness of the UK for international researchers and the high volume of international collaborative activities, which could be threatened by BREXIT. It was noted that many institutions are already reporting slow recruitment from Europe, reducing the high skillset within the UK. It is important that care is taken at this special time to maintain the world class UK nuclear physics programme.

Science & Technology Facilities Council

Annex 1

Ranking Scoresheet for Programme Evaluations 2018/19

During the 2017/18 Programme Evaluations, projects/experiments/facilities within each discipline will be ranked. The ranking criteria will cover scientific excellence, exploitation within grants, and impact/industrial engagement. The exercise will look at all funded projects/experiments/facilities and ensure each is considered at whatever its stage of the exploitation cycle.

The panels will consider the merits or otherwise of supporting areas currently receiving STFC investment. This will include consideration of international engagement and subscriptions.

The ranking criteria will be largely based on that previously used by STFC, namely **α** rankings for projects/experiments and “g” rankings for science exploitation themes within grants as used in the last Programmatic Review. In addition a new “i” ranking will be introduced to cover evaluation of impact for the economy and society.

The Panel will be asked to consider the strategic value of the projects/experiments/ facilities that submitted proformas and how highly aligned they are to the mission of STFC. Consideration should also be given to the international standing and the potential for leadership of the area under review. Additional value, such as synergies within the STFC frontier science disciplines (Particle Physics, Astronomy, Nuclear Physics, Particle Astrophysics, Computing, Accelerators) programme should also be taken into account.

The Panel will be asked to score each of the projects/experiments/facilities on the following criteria and submitted 2 days before the meeting.

The Panel member should complete section 1 and 4 below for each proforma. A marking should be given for either section 2 or 3 dependent on which is most appropriate.

The below wording is generic for the six evaluations and may be slightly modified to suit the specific requirements of the individual reviews.

1. **What is the life cycle stage of the Project/Experiment/Facility?**

Early / Developing / Mature

2. **Scientific Excellence of Project/Proposal**

α5 - Highly innovative and very likely to result in seminal changes in knowledge.
α4 - Likely to substantially advance the subject.
α3 - Likely to make an important contribution to the subject.
α2 - Competent, worthy science.
α1 - Interesting science but outcomes considered doubtful.
β - Poor quality, flawed or unlikely to deliver meaningful or interesting results.

3. **Exploitation**

Projects in the science exploitation phase are funded via grant panels. Three categories are defined, intended as strategic guidance to the peer review carried out by grant panels. Please consider the value of exploitation when the area under evaluation reaches maturity.

g3 - A project with high strategic importance in the STFC programme, which has received substantial investment. We would expect to see it adequately funded via grants after peer review
g2 - A project with high potential for excellent science which should be considered via peer review
g1 - A project which is not well matched to the STFC programme, we would be surprised if it were to receive funding via the grants panel.

4. **Impact and Engagement**

Please consider if there is important impact within industry and/or wider society that STFC should be looking to exploit and that will otherwise not happen elsewhere.

i5 - Very exciting impact already under IP management or a close working partnership or exchange with non-academic partners is already in place.
i4 - Very exciting opportunities proposed, with some first connections made.
i3 - Interesting opportunities suggested but needs significant further work.
i2 - Little opportunity, although some could evolve in near future.
i1 - Little opportunity and unlikely to develop significantly in near future.
i0 - No apparent opportunities at all.