FORM FOR THE SUBMISSION OF EVIDENCE

Please complete and return this form to MathematicsIntReview@epsrc.ac.uk by **30th September 2010.** You must limit your submission to no more than 8 pages in length and no smaller than font size 11. *Information submitted on this form will be published on our website unless agreed in advance in which case you must clearly state that the form contains confidential content for the panel only and indicate which information on the form is to be treated as confidential.*

The purpose of this review is to benchmark UK research activity in mathematical sciences against the rest of the world, and it will be used to help inform future strategy and funding policy. It is *not* a review of individual institutions or researchers. Please therefore ensure that your comments address and illuminate for the panel the UK-level issues flagged in the attached evidence framework (see Annex A).

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Statement of interest (please indicate your reasons for making this submission - 200 words max.):

The London Mathematical Society (LMS) is the major UK learned society for mathematics set up for the advancement, dissemination and promotion of mathematical knowledge. It was founded in 1865 for “the promotion and extension of mathematical knowledge” and was granted a Royal Charter in 1965.

The aims of the LMS are:

- To advance the interests of mathematics.
- To enable mathematicians to research and collaborate to advance mathematical knowledge.
- To make mathematical knowledge available worldwide.
- To promote mathematical research and its benefits to decision-makers, policy advisers, funders and the users of mathematics.
- To support mathematical education in schools, colleges and universities, and encourage the public and young people to appreciate and engage with mathematics.

The support of mathematical research is one of the primary aims of the LMS, which is widely informed in this area, representing as it does some 2,000 UK mathematicians as well as over 500 overseas members. The LMS is at the forefront of discussions on the current state of mathematical research and is currently preparing a set of policy statements on mathematical research. The first three of these statements, in addition to the completed questionnaire, will be offered to the Panel for consideration; they will be submitted to the Panel once approved by the Council of the LMS at its meeting on 8 October 2010. Some of the points made below are discussed in more detail in the policy statements.

A. What is the standing on a global scale of the UK Mathematical Sciences research community both in terms of research quality and the profile of researchers?

UK Research activity in the mathematical sciences was rated very highly in RAE2008, with 49% or more of research activity[1] in each of the three relevant subject areas being rated as **internationally excellent** (3*) or **world-leading** (4*). Eminent international mathematical scientists were members of each of the three mathematical science sub-panels. Two additional features are worthy of note in the table below:

- Performance is very similar across all three disciplines.
- Excellence is widespread throughout the research community, not being concentrated only in a small number of large submissions.

	%4*	%3*	%2*	%1*
Pure: all submissions	14	39	39	6
Pure: biggest 4 submissions	30	43	26	1
Pure: biggest 8 submissions	22	39	30	6
Applied: all submissions	12	37	38	13
Applied: biggest 4	26	45	29	0
Applied: biggest 8	24	43	31	2
Statistics+OR: all submissions	14	40	37	9
Statistics+OR: biggest 4	22	45	29	4
Statistics+OR: biggest 8	22	44	30	3

Evidence from the RAE also indicates that the **volume** of research activity in UK mathematical sciences increased in the period 1997-2007: 1783 FTE were submitted to the three mathematical sciences sub-panels in RAE2001, 1946 FTE in RAE 2008, an increase of 9%.

Citation indices are widely recognised to be a rather unreliable means of judging performance in the mathematical sciences, at the level of individual researchers, or small groups of researchers. Nevertheless, when one is dealing with normalised indices at the scale of a country's output, they offer a useful guide to research strength. As such, they provide a second indicator of the strength in depth of UK mathematical sciences in an international context at the start of the 21st century – the

[1] Averages in the table (and hence also the 49% figure) are taken over submissions – that is, they are *not* weighted by the size of submissions.

[2] See **http://www.timeshighereducation.co.uk/story.asp?sectioncode=26&storycode=406463**
Denmark and the USA are respectively first and third.

Thomson Reuters Citations Top 20, for mathematical sciences 1998-2008, shows Scotland in second place, England in fourth[2].

Notwithstanding the current high quality of research performance noted above, the UK spends much less on the mathematical sciences relative to other disciplines (such as physics) than is typical for a developed country, and future funding cuts threaten the (currently excellent) quality and amount of UK mathematical sciences research.

B. What evidence is there to indicate the existence of creativity and adventure in UK Mathematical Sciences research?

All research of high quality in the mathematical sciences is both creative and adventurous: it is self-evident that creativity is a key component of the process of doing such research, and risk is also inherent, since it is never certain in advance that a project will achieve success. A further noteworthy and often overlooked feature of fundamental research is the length of time before pay-off: in the mathematical sciences the time gap can often be extremely long.

The past 20 years have seen a great flowering of mathematics worldwide, and UK-based mathematicians have been prominent in that activity at the highest level. These contributions have indeed been internationally recognised: for example, Borcherds and Gowers were awarded Fields medals in 1998, Donaldson the King Faisal Prize (2006), the Nemmers Prize (2008) and the Shaw prize (2009); and Atiyah the Abel Prize (2004).

But below these exalted heights there is plentiful evidence of the continuing broad strength of UK mathematical sciences in an international context, for example from the citation figures already quoted, or from the publication records of UK-based researchers in the top journals, and in the pattern of international collaboration of mathematical scientists based in the UK.

C. To what extent are the best UK-based researchers in the Mathematical Sciences engaged in collaborations with world-leading researchers based in other countries?

Most UK-based mathematical scientists are members of active international collaborations, as can easily be seen from a cursory check on publication records, although we are not aware of any figures detailing precise numbers. The simple fact is that this is an accepted fact of everyday life for the modern-day research mathematician – the subject is truly international.

For some mathematical scientists, such collaborations are supported by their Research Council grants, but a much greater proportion receive financial support from their own institutions to attend conferences, invite potential and current collaborators to their own institutions, and to make short research visits abroad. The existence of this research support is a direct consequence of the Dual Support mechanism for university research in the UK.

A great deal of **support for these research activities** is also provided by the **learned societies**, the London Mathematical Society (LMS), the Institute for Mathematics and its Applications, the Royal Statistical Society, the Edinburgh Mathematical Society, and the Royal Society. Details of the various grant schemes of the LMS can be found at **http://www.lms.ac.uk/**. In the financial year 2009-10, the LMS awarded a total of £294,302 through these schemes, a figure which has shown an increase every year from the £195,292 awarded in 2005-6.

Of course, it is far from the case that the benefits of this support all flow in one direction. For example, The LMS supports and manages a programme for Africa in conjunction with the **International Mathematical Union** and **African Mathematics Millennium Science Initiative** to mentor young African mathematical researchers, teaming them with active mathematical researchers from institutions from established countries around the world, including the UK. The programme is sponsored by the Nuffield Foundation and the Leverhulme Trust.

A huge amount of foreign interaction with UK mathematical sciences also arises under the auspices of the **Isaac Newton Institute (INI)** (Cambridge) and the **International Centre for Mathematical Science (ICMS)** (Edinburgh)**.** The activities of these institutions are complementary in character, the first focussing on long programmes, the second typically running meetings of up to a week in length – but each makes a crucial contribution to the health of UK mathematical science, and greatly increases its international connectivity. While the LMS and other organisations strongly supports both INI and ICMS, (for instance by providing funds for promising early career researchers to attend their programmes), continued Research Council support is key to their continuing roles of encouraging and facilitating leading-edge national and international collaborative research in mathematics. And to an important and indeed fast-growing extent, both INI and ICMS provide Knowledge Exchange (KE) and Knowledge Transfer support for the activities of UK-based mathematical scientists.

D. Is the UK Mathematical Sciences community actively engaging in new research opportunities to address key technological/societal challenges?

Many examples can be given of explosive, practical applications delivered from mathematics developments ranging from the purest to the most applied. To give only a few examples from the many which could be mentioned, many of the UK's number theorists, combinatorialists and geometers have been involved over recent years in the activities of the Heilbronn Institute; mathematical biologists at Dundee have developed a new radiotherapy protocol for breast cancer; and statisticians at Cambridge are working on stochastic networks, with key applications as diverse as road transport policies and the future of the internet.

E. Is the Mathematical Sciences research base interacting with other disciplines and participating in multidisciplinary research?

There is indeed a great deal of interaction with researchers in other disciplines: there are large numbers of ongoing research projects involving UK-based mathematical scientists working with biologists, medical scientists, engineers, computer scientists, and environmentalists, and the IRM Panel will certainly hear detailed accounts of many of these vitally important projects in the course of their week in the UK, and via the returns from individual institutions.

Having stated the above basic fact as clearly as possible, we wish to use this space to make a related but different point: the LMS believes that the best way to foster more such activity of the highest quality is **not** for EPSRC to reduce further the already fast shrinking amount of funding available through Responsive Mode, with the aim of thereby providing instead funds for specific interdisciplinary programmes. Many of the key interdisciplinary contributions of the mathematical sciences arise from pieces of **fundamental** mathematical research – one thinks for example of the work by Radon and Fritz John (1917, 1938), which was instrumental much later in the development of tomography. It is crucial for the chances of success of future interdisciplinary projects that EPSRC maintains substantial support for fundamental research in the mathematical sciences.

F. What is the level of interaction between the research base and industry?

The **INI and the ICMS** both actively encourage industry to engage with their mathematical research programmes, and – conversely – support schemes to enable participants in their programmes to engage with prospective industrial partners. Both institutions employ staff for whom KE and Knowledge Transfer activity is a key part of the job description. Both have held a number of recent workshops and programmes for which engagement with industrial partners was a central component, as we are sure their submissions will explain in some detail. Moreover, many individual researchers have ongoing research collaborations with industrial partners.

However, there is no doubt that the most important and most fundamental contribution of UK-based mathematical science to the UK's industrial base is through **training** – that is, through the education of large numbers of highly trained mathematical science undergraduates (more than 5000 per year), graduates with masters, and graduates with doctorates (over 400 per year). The majority of these people move directly into the industrial and financial sectors. The continued health of this pipeline, both as regards quantity and as regards quality, is vital for the economic future of the UK.

We believe that there is a **severe risk** that, if faced by continuing cuts in the Research Council support for research in the mathematical sciences of the scale encountered in the past two years, (which have seen Responsive Mode funding cut from more than £20M, to £14.3M in 2009-10 and less than £7M in 2010-11), then university administrations attempting to maximise their income streams through Full Economic Costing will simply shut down mathematical science departments. This will result in large areas of the UK becoming mathematical deserts, with no high quality mathematics training available, and with hugely detrimental consequences for industry.

G. How is the UK Mathematical Sciences research activity benefitting the UK economy and global competitiveness?

We have nothing to add to the points already made in D, E and F.

H. How successful is the UK in attracting and developing talented Mathematical Sciences researchers? How well are they nurtured and supported at each stage of their career?

A. Educational pathways: According to HESA statistics, there were 34,120 students in UK higher education in 2007-8. There was a steady increase in this figure from the 30,105 in 2003-4. This is a 13.3% increase, compared with an overall 4.8% increase across the whole sector in the same time period. We briefly review below the key stages.

Undergraduate degrees: About 5300 students graduate in the UK with undergraduate degrees in mathematics in each year (2007-8 figures). Recruitment has been buoyant for some time, and mathematical science graduates are in high demand from employers - HESA data from 2007-8 gives the average salary of a mathematical sciences graduate 3.5 years after graduation as £25.7K compared with an average across all subjects of £22.9K. As stated earlier, a wide geographic spread of strong mathematical sciences departments across the UK is vital for the continued health, and indeed the much-needed expansion, of the UK's efforts in educating undergraduate mathematical scientists.

Masters degrees: There is a great dearth of masters degree programmes in the mathematical sciences in the UK, even in more applied areas where more financial support was provided in former times. In contrast to the situation for mathematics, masters studentships in statistics and operational research are still provided (the money for this has been top-sliced from the mathematical sciences Doctoral Training Account (DTA)), and indeed there is a clear strategic need for this; however, all EPSRC funding for masters courses in applied/industrial/computational mathematics has ceased. These courses provide an excellent training (for a career in UK industry or as preparation for a PhD), and are now inaccessible to all but a very few potential UK students (the standard undergraduate student loans scheme does not apply to stand-alone masters courses). The IRM Panel may well wish to review the state of masters degree education in the UK.

PhDs: Between 400 and 450 doctorates are awarded in the mathematical sciences in the UK each year. Demand for places for doctoral study is high, and the key constraint on recruitment numbers of home students in most subfields of the mathematical sciences is the scarcity of financial support for students. We mention some specific issues concerning PhD training in the mathematical sciences in the UK.

- There is a severe potential threat from the imminent financial cuts to EPSRC DTA funding (which currently provides the bulk of financial support to UK-based postgraduate students in the mathematical sciences). Any non-trivial reduction in this already low sum (£11M from EPSRC in 2009-10) would have disastrous effects, not only on the production of highly qualified mathematical scientists, but in the well-being of UK academic mathematical science.
- The role of peer review in assigning mathematical science DTA funds to institutions is an important distinguishing feature of the present system. This should not be replaced by the sort of metric-based approach used in some other fields.
- Further hazards in the conversion of DTA funds to actual support for PhD students result from the fact that EPSRC rules permit individual universities to vire DTA funds, awarded by peer review to the mathematical sciences at that institution, to other fields – this is a highly unsatisfactory state of affairs.
- The process whereby students are recruited to departments is haphazard and *ad hoc,* and indeed is probably no longer fit for purpose.
- The introduction by EPSRC in 2008 of Centres for Doctoral Training (CDTs, although initially called DTCs) had no initial impact on the mathematical sciences; but now 3 of the approximately 50 CDTs are in the mathematical sciences. It would be fair to say that there is a great deal of ambivalence about this development in the community – while the extra PhD places are welcome, there is considerable fear that there will be a corresponding reduction in DTA funds in due course. There are also doubts over the cost-effectiveness of CDTs as compared with PhDs supported through DTAs (estimated cost of a 4-year CDT PhD is £100K, as compared with about £65K for a 3.5-year DTA-funded PhD). Nor is it clear that the further concentration of precious resources in narrow subject ranges and in concentrated geographic locations is the correct strategy for postgraduate training in the mathematical sciences in the UK.

Postdoctoral positions: There is no doubt that UK mathematical science has benefited greatly from the influx of foreign talent to permanent academic posts over the past 20 years, but this is not a pattern that can or should continue indefinitely. To maintain a steady state in UK mathematical science departments while at the same time providing a good supply of PhD mathematical scientists to the wider economy, we calculate that there should be around 500 UK PhDs in the mathematical sciences each year. The next stage in the pathway to academic positions is critical – simply to maintain current numbers of academics, about 100 postdoctoral positions in mathematical science are needed each year. The Postdoctoral Fellowship Scheme supported by EPSRC is very successful, but yields only about 12 positions each year. The number of EPSRC "responsive mode" awards in the mathematical sciences including a research assistant will be at most 20 in 2010-11 (given the budgeted responsive mode funds of £7M). There are of course a number of Research Fellowships and Research Assistantships funded through directed calls from EPSRC, through other Research Councils and through College endowments and the like – but the grand total is still a long way short of 100.

I. Other Comments – Please use this space to provide any additional information which you believe would be useful for the Review Panel

The key points we wish to emphasise are these:

- The UK's research performance in mathematical science has been excellent in the period since the last International review in 2004. The quality of research produced has been maintained, and there has been some increase in volume.
- This excellent performance is under severe threat. There have already been very large cuts in Research Council support for research in the mathematical sciences. Not only will this result in reductions in the quality and quantity of the research produced in the UK, but it will also (as discussed in H) seriously damage the already inadequate pathways to academic careers in the UK. However, a further threat lie beyond these: given the current and impending pressures on university finances, we face the prospect in this era of Full Economic Costing that university administrations will invest only in fields where there is a realistic prospect of large grant awards. The consequences of such a shrinking of the UK's mathematical science profile would be severe, not only for our research performance but also for the education of a mathematically-trained workforce in the UK.

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EVIDENCE FRAMEWORK

A. What is the standing on a global scale of the UK Mathematical Sciences research community both in terms of research quality and the profile of researchers?

- Is the UK internationally leading in Mathematical Sciences research? In which areas? What contributes to the UK strength and what are the recommendations for continued strength?
- What are the opportunities/threats for the future?
- Where are the gaps in the UK research base?
- In which areas is the UK weak and what are the recommendations for improvement?
- What are the trends in terms of the standing of UK research and the profile of UK researchers?

B. What evidence is there to indicate the existence of creativity and adventure in UK Mathematical Sciences research?

- What is the current volume of high-risk, high-impact research and is this appropriate?
- What are the barriers to more adventurous research and how can they be overcome?
- To what extent do the Research Councils' funding policies support/enable adventurous research?

C. To what extent are the best UK-based researchers in the Mathematical Sciences engaged in collaborations with world-leading researchers based in other countries?

- Does international collaboration give rise to particular difficulties in the Mathematical Sciences research area? What could be done to improve international interactions?
- What is the nature and extent of engagement between the UK and Europe, USA, China, India and Japan[3], and how effective is this engagement?
- How does this compare with the engagement between the UK and the rest of the world?

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[3] The countries listed have been identified as strategically important international research partners for the UK

D. Is the UK Mathematical Sciences community actively engaging in new research opportunities to address key technological/societal challenges?

- What are the key technological/societal challenges on which Mathematical Sciences research has a bearing? To what extent is the UK Mathematical Sciences research community contributing to these? Are there fields where UK research activity does not match the potential significance of the area? Are there areas where the UK has particular strengths?
- Are there any areas which are under-supported in relation to the situation overseas? If so, what are the reasons underlying this situation and how can it be remedied?
- Does the structure of the UK's mathematical science research community hamper its ability to address current and emerging technological/societal challenges? If so, what improvements could be implemented?
- Are there a sufficient number of research leaders of international stature in the Mathematical Sciences in the UK? If not, which areas are currently deficient?

E. Is the Mathematical Sciences research base interacting with other disciplines and participating in multidisciplinary research?

- Is there sufficient research connecting mathematical scientists with investigators from a broad range of disciplines including life sciences, materials, the physical sciences, finance and engineering? What is the evidence?
- Where does the leadership of multidisciplinary research involving mathematical sciences originate? In which other disciplines are the mathematical sciences contributing to major advances?
- Are there appropriate levels of knowledge exchange between the Mathematical Sciences community and other disciplines? What are the main barriers to effective knowledge and information flow, and how can they be overcome?
- Have funding programmes been effective in encouraging multidisciplinary research? What is the evidence?

F. What is the level of interaction between the research base and industry?

- What is the flow of trained people between industry and the research base and vice versa? Is this sufficient and how does it compare with international norms?
- How robust are the relationships between UK academia and industry both nationally and internationally, and how can these be improved?
- To what extent does the Mathematical Sciences community take advantage of opportunities, including research council schemes, to foster and support this knowledge exchange? Is there more that could be done to encourage knowledge transfer?
- Nationally and internationally what is the scale of Mathematical Sciences R&D undertaken directly by users? What are the trends? Are there implications for the UK Mathematical Sciences research community, and how well positioned is it to respond? Is there any way that its position could be improved?

G. How is the UK Mathematical Sciences research activity benefitting the UK economy and global competitiveness?

- What are the current and emerging major advances in the Mathematical Sciences area which are benefiting the UK? Which of these include a significant contribution from UK research?
- How successful has the UK Mathematical Sciences community (academic and user-based) been at wealth creation (e.g. spin-out companies, licences etc.)? Does the community make the most of opportunities for new commercial activity? What are the barriers to successful innovation based on advances in the Mathematical Sciences in the UK, and how can these be overcome?

H. How successful is the UK in attracting and developing talented Mathematical Sciences researchers? How well are they nurtured and supported at each stage of their career?

- Are the numbers of graduates (at first and higher degree level) sufficient to maintain the UK Mathematical Sciences research base? Is there sufficient demand from undergraduates to become engaged in Mathematical Sciences research? How does this compare with the experience in other countries?
- Is the UK producing a steady-stream of researchers in the required areas or are there areas of weakness in which the number of researchers should be actively managed to reflect the research climate. What adjustments should be made?
- How effective are UK funding mechanisms at providing resources to support the development and retention of talented individuals in the mathematical sciences?
- How does the career structure for researchers in the Mathematical Sciences in the UK compare internationally?
- Is the UK able to attract international researchers in the Mathematical Sciences to work the UK? Is there evidence of ongoing engagement either through retention within the UK research community or through international linkages?
- Are early career researchers suitably prepared and supported to embark on research careers?
- Is the balance between deep subject knowledge and ability to work at subject interfaces/boundaries appropriate?
- How is the UK community responding to the changing trends in the UK employment market?
- How diverse is the UK mathematical sciences research community in terms of gender and ethnicity and how does this compare with other countries?