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 Edinburgh Mathematical Society (EMS) is the principal mathematical society for the university community in Scotland. Its aims are: "the promotion and extension of the Mathematical Sciences, pure and applied, particularly in Scotland".

The reason for this submission is to describe mathematical sciences research in Scotland in the context of that for the UK as a whole, because of the differences in education systems and funding. Hence most answers below **refer to Scotland rather than the UK as a whole.**

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?

Scotland comprises 8.4% of the total UK population, but submitted 12.8% of the mathematical sciences academic researchers in the 2008 Research Assessment Exercise (RAE) – 248 academic staff in the Units of Assessment for Pure Mathematics, Applied Mathematics, and Statistics & Operational Research, out of a UK total of 1940. The overall performance of Scottish mathematical sciences in RAE 2008 in comparison with the overall UK results are summarised in the table below (grade 4* in the RAE denoted "world leading" and 3* "internationally excellent").

weighted % in:	4* (Scotland)	4* (UK)	4*+3* (Scotland)	4*+3* (UK)
Pure	19.3	18.2	61.2	58.1
Applied	13.8	16.7	57.0	59.1
Stats & OR	11.1	17.0	47.0	59.0
Total	15.0	17.3	56.0	58.7

The results show the quality of Scottish research to be excellent, especially in pure mathematics, although the Scottish performance at the top, world-leading end of the range in applied mathematics and statistics & OR is slightly below the UK average. When the individual UK submissions are ordered by "quality rating", Q, (a weighted average of the quality profile), then the top Scottish submission is 6th in the UK in pure mathematics (out of 38), 4th in applied mathematics (out of 46), and 14th in statistics & OR (out of 31). [These are the rankings based on the Q-weightings used by SFC and in 2009-10 by HEFCE. HEFCE's 2010-11 weightings give the top Scottish positions as 6th, 5th, and 15th, respectively.]

Scotland also performs well in bibliometric studies – e.g. the Times Higher (7 May 2009) published a table showing Scotland to be second in the world ranking of mathematical sciences citations per research paper, ahead of both the US and England (although care needs to be taken in any interpretation of citation counts).

Scotland is host to the International Centre for Mathematical Sciences (ICMS), the sister organisation of the Isaac Newton Institute (INIMS). The two perform complementary roles: INIMS running 2-3 long programmes and ICMS running 15 or so workshops per year. The two centres are the UK members of ERCOM, the umbrella organisation for European Research Centres. The mathematical standard of ICMS workshops is extremely high as indicated by the comments of the international experts who are asked to referee proposals, while both the academic and organisational quality of the workshops is attested to by the exceptionally favourable responses of participants.

Scottish departments have had considerable success in attracting large grants in the decade from 2000. These include awards for two EPSRC multidisciplinary critical mass centres (out of 6 funded); two EPSRC science and innovation awards (out of <10 funded in mathematical sciences); a significant (£1.7M) 'rolling grant' and share of £2.4M for high performance computing from STFC; and an €1.7 Million EU Advanced Investigator award. Many of these awards are collaborative, involving other disciplines or more than one institution. Even the largest Scottish mathematical sciences departments are dwarfed by the larger English departments, but collaboration enables Scottish departments to compete for research funding with institutions from England or overseas. It is thus profoundly damaging to the health of the discipline in Scotland that the Scottish Funding Council (SFC) is no longer in a position to fund a mathematical sciences "research pool", because of UK public funding cuts (for information on SFC's pooling initiative and a list of funded disciplines see **www.sfc.ac.uk/research/researchpools/researchpools.aspx**).

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. In fact, Scottish departments are especially vulnerable, because SFC has already cut mathematical sciences research funding by about 25% over the past two years (this was due to a change in funding methodology; see Section I for more information). Further funding cuts pose a severe threat to the health of the discipline, especially when combined with concentration of funding into far fewer departments. The EPSRC Mathematical Sciences Programme's new invitation-only "platform grant" scheme was particularly disappointing in this regard: it was restricted to the top 5-6 UK departments as measured by grant income from that EPSRC Programme. (No Scottish departments were allowed to apply under this scheme.)

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

Mathematics research is inherently **risky/adventurous** in that plausible proposals may founder on the rocks of mathematical rigour when the research is actually undertaken. Unlike a clinical trial, which might conclude that a plausible new variant of an existing drug is or isn't worth developing (both of which are useful research outcomes), the outcome of an exciting mathematics proposal may be very limited if it turns out that crucial technicalities cannot be overcome. High-quality research in the mathematical sciences is necessarily **creative**, and so in particular all the comments in Section A above about research quality apply here as well.

- One very important **positive** aspect of EPSRC's policies is the existence of a separate Mathematical Sciences Programme. The Programme team's support is extremely valuable in initiatives which are crucial for a "people-based" subject like mathematical sciences, such as post-doctoral fellowships, allocation of DTA studentships by peer review, and funding for the Newton Institute and ICMS.
- The requirement for detailed project specifications for "responsive mode" applications may make sense for experimental projects with very expensive equipment, but it is **not particularly suitable** for the mathematical sciences.
- The **most detrimental aspect** of EPSRC's funding policy towards mathematical sciences is the size of the funding pot: less than £7M for responsive mode mathematical sciences research in 2010-11 for the whole of the UK. The reason for such low levels of funding (compared to that given to ICT, chemistry, physics, engineering) is not clear: by any rational measure (UG student population, academic staff numbers, research quality, research output) we are a large and important discipline, but are persistently funded in the UK as a (very) small one.

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?

A high proportion of Scottish-based mathematical sciences researchers have international research collaborations. Such linkages are an important and commonplace feature of mathematical sciences research worldwide. There is widespread research interaction between members of Scottish mathematical sciences departments and colleagues in Europe (including fSU countries), USA and Asia, including China and Japan. There are also research links with the English-speaking Commonwealth, countries in S America, and probably others.

Many of these international research collaborations are only possible because of the existence of "small grant" schemes, such as those provided by learned societies (e.g. LMS, IMA and EMS) and the EPSRC Mathematical Sciences Programme's (responsive mode) small grants call. These schemes are extremely valuable, and any cuts would have long-term implications for UK mathematical sciences research.

More formal involvement of Scottish-based researchers in international projects includes membership of European training networks and the (EPSRC-funded) French-British network in representation theory.

International collaboration across the UK is greatly facilitated by both the Isaac Newton Institute and the International Centre for Mathematical Sciences (ICMS). Scotland is fortunate to be home to ICMS, which facilitates a programme of research workshops and conferences for UK mathematics at the top international level.

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

It is hard to think of a key technological/societal challenge on which mathematical sciences research does not have a bearing. Recent Scottish examples of research with immediate impact include: statistical epidemiologists adapting strategies for pandemic influenza; the development by mathematical biologists of a new radiotherapy protocol for breast cancer; in energy, new mathematical models and numerical algorithms which are improving both the efficiency of oil and gas extraction as well as the operation of renewable and traditional energy markets; in finance, sound quantitative risk management is helping Scottish institutions to restructure and will be essential for developing effective regulatory procedures; in communications, work on predicting space weather is helping to protect communications satellites (which cost millions of pounds to replace). Scottish-based researchers also participate in research activities at the Heilbronn Institute.

Many of these key areas have been supported by recent INI programmes or ICMS workshops. Examples include the INI programmes on "Mathematical and Statistical Approaches to Climate Modelling and Prediction" and "Stochastic Processes in Communication Sciences", and ICMS workshops on "Nonlinear PDEs arising in mathematical biology: cell migration and tissue mechanics", "Stochastic Processes in Communication Networks" and "Reconstructing and understanding climate change over the last few millennia and the holocene epoch".

The payback from fundamental mathematical sciences research is often over a far longer term, and because of long lead times it is often difficult to predict the areas in which the impact of more theoretical results will be realised. All excellent mathematical sciences research has the potential to make a significant technological and economic impact in the short, medium or long term.

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

Scottish-based mathematical sciences researchers are heavily engaged in multidisciplinary research with investigators from many other disciplines. Examples include the following.

- **life sciences:** ecology, cancer modelling and treatment protocols; Biomathematics and Statistics Scotland (BioSS); systems biology; epidemiology
- **materials:** liquid crystal and other anisotropic materials; metamaterials
- **physical sciences:** solar physics; molecular dynamics; condensed matter physics; plasma physics
- **computer science and HPC:** the GAP computational algebra system; Centre for Numerical Algorithms and Intelligent Software
- **finance:** the new Scottish financial risk academy
- **engineering:** oil & gas; groundwater flow; non-destructive testing

This high-level of interaction is supported by INI programmes and ICMS workshops. Recent examples include the INI programmes on "The Cardiac Physiome Project" and "Gyrokinetics in Laboratory and Astrophysical Plasmas", and ICMS workshops in "Recent Developments and New Directions in Thin-Film Flow" and "Mathematical Neuroscience", as well as those given in Section D above.

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

Formal interaction between Scotland's mathematical sciences researchers and industry takes a variety of forms, including joint supervision of CASE PhD students, industrial PhD internships, KTP/TCS schemes, provision of professional courses (CPD) and private consultancy.

Many recent ICMS workshops have been related to industrial applications (e.g. "Applications of Maths in the Energy Sector" and "Marine and Tidal Energy Workshops"), and interaction between Scotland's mathematical scientists and industry has been aided by the dedicated knowledge transfer officer (KTO) based at ICMS. One objective of ICMS's knowledge transfer activities is to facilitate the creation of projects where businesses and academics collaborate to use mathematics and statistics to solve problems and drive business innovation.

However, in common with other disciplines (see G below), the primary interaction is in the movement of highly-trained students (with BSc, Masters and PhD) and postdoctoral researchers into industry and business. Our graduates are in great demand, and this is the main way in which high-level mathematical sciences expertise is transferred from universities into industry.

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

As noted in the League of European Research Universities (**www.leru.org**) publication "What are Universities For?": *University commercialisation activities themselves, the creation of spin-out and start-up companies and licensing of intellectual property, do not, even in the USA, where university commercialisation is best developed, directly contribute significantly to GNP.* The substantive impact that Higher Education does make to UK wealth creation is predominantly through educating the workforce – the same LERU publication quotes a study which concludes that it is: *the quality of staff at all levels that is the most important determinant of business competitiveness.*

UK mathematical science graduates, post-graduates and post-doctoral researchers are extremely highly prized by employers – so much so that a table in the recent (UK) Department for Business Innovation & Skills Postgraduate Review report (**www.bis.gov.uk/postgraduate-review**) lists mathematical sciences PhD graduates as having the highest average salary over PhDs in all disciplines (information was collected six months after graduation in 2007-08). This indicates that the mathematical sciences are likely to have a significant impact on wealth creation, since many UK graduates (at first degree and PhD level) enter employment in business and industry. Anecdotal evidence backs this up – for example, the contribution of a senior executive from a leading US oil company to a discussion on how best to transfer new ideas from academic research into his and other companies was clear: the most effective process is for universities to train students (BSc, Masters and PhD) and other young researchers in the most recent techniques and models, and the knowledge will be transferred to industry by the people who go to work for them.

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?

- **Undergraduate.** Scotland's universities typically have few problems in recruiting mathematical sciences undergraduates; most could admit far more but are prevented from doing so because of Funding Council caps. The UK total of around 5300 mathematical sciences graduates per annum (this is the 2007/08 figure) is substantial and is equal to that for physics and chemistry combined.

- **Masters.** Up until a few years ago (when the "Collaborative Training Account" scheme was replaced by the "Knowledge Training Account"), EPSRC provided support (fees + stipends) for masters courses in mathematical sciences and other disciplines. This support was withdrawn without any obvious prior consultation with the academic community (certainly none with any of the mathematical sciences learned societies) and has been profoundly damaging. 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), and there is a clear strategic need for this, but 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).

- **PhD funding.** Most EPSRC funding for mathematical sciences PhD students is provided via the Doctoral Training Account (DTA): this pays a stipend, fees and some research support for 3.5 years. It is allocated by peer review, rather than algorithmically on the basis of grants awarded (which is the allocation mechanism for all other disciplines), but is awarded to universities, who are free to allocate less (or more) to their mathematical sciences departments.
  There was a big shift in EPSRC's overall PhD funding in 2008, with the establishment of 44 Doctoral Training Centres – DTCs (the terminology now seems to be Centres for Doctoral Training – CDTs). The management of this massive programme was such that **none** were awarded in mathematical sciences, and very few in fundamental science. Funding was found for a separate mathematical sciences call the following year, and there are now three new CDTs. Whilst these extra mathematical sciences PhD places are welcome, it is perhaps an understatement to say that the UK community has reservations about the CDT model. Its main attraction is that students are funded for 4 years, with the first year to include a broad, formal training, but it does not seem to be a very cost-effective way to achieve what many would regard as the ideal training environment. (The typical cost of a 3.5 year PhD under the DTA is about £65,000, which would equate to around £75,000 for 4 years. In contrast, about £100,000 per 4-year PhD appears to be more typical for a CDT.)

- **PhD training.** The recruitment and training of mathematical sciences PhD students in Scotland received a significant boost in 2007 with the inauguration of the Scottish Mathematical Sciences Training Centre (SMSTC, www.smstc.ac.uk), funded by EPSRC (it is one of the six UK PhD mathematical sciences Taught Course Centres; they were a direct consequence of recommendations made by the 2004 International Review Panel). The SMSTC provides a carefully structured portfolio of eight advanced courses, delivered by video-link from any one of the participating departments, to groups of students around Scotland. A selection of these courses is taken by almost all our new PhD students in the first six months of their degree. The aim is to offer something comparable to what might be seen in the first year of PhD studies at a good North American department, or at the beginning of the troisieme cycle in continental Europe. SMSTC is run by an Academic Management and Steering Group drawn mainly from the participating departments. Its administration is handled by ICMS, and this support (for student registration, the website, organising the two annual symposia, booking videoconference sessions, and meeting paperwork) has been essential for the smooth running of SMSTC. Early indications are that SMSTC has performed well in the review of all the Taught Course Centres commissioned by EPSRC.

The Scottish mathematical sciences departments also run a collaborative programme of "generic skills" activities for their postgraduate students. This programme was initiated by the EMS and ICMS, and is now administered by ICMS and paid for by the institutions from their Research Council "Roberts' funding". (The future of this funding source is unclear.) Other events for graduate students include an annual EMS postgraduate conference (at the Burn House), which is also administered by ICMS, and several student-run meetings (typically funded by LMS and/or EMS).

- **Postdoctoral.** Perhaps the greatest threat to the discipline comes from the very small number of postdoctoral positions available to new PhD graduates. EPSRC's postdoctoral fellowship scheme is very valuable, but typically can only fund around 12 new positions per year. Many of the other positions available are to work on specified research projects funded by EPSRC "responsive mode" grants – and with total responsive mode funding of less than £7M in mathematical sciences for 2010-11, this will only add around 25 new postdoctoral positions (for the UK as a whole). Not only is this figure very low, there is no guarantee that the funded research projects will either match the research areas of the majority of outstanding PhD graduates, or cover a broad range of mathematical sciences research. There used to be a reasonable number of temporary research/teaching positions in departments around the UK available to recent PhD graduates, but anecdotal evidence is that there are now far fewer of these, possibly as a result of changes to employment law (which guarantee a permanent contract after a few years in post).

- In common with the rest of the UK, Scottish departments greatly benefit from having been able to recruit and retain academic staff from around the world.

- Academic staff are under increasing pressure from university managements to bring in research grant income, with some institutions using increasingly blunt "performance indicators" in annual review. The low levels of mathematical sciences research funding makes it harder for heads of department/school to argue for new or replacement staff (in competition with disciplines which typically bring in more per capita income into the institution in the way of overheads etc.), despite a strong track record in making excellent appointments. This situation is further exacerbated in Scotland where a large percentage of the Scottish Funding Council's (RAE-based) research support is awarded on the basis of grant income and postdoctoral and research student numbers.

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

The education system in Scotland differs greatly (both in structure and funding) from that in other parts of the UK, and this section provides a brief overview.

- **School.** The main qualifying exams in Scotland for university admissions are Highers (typically taken a year before English students take A-levels), although many students stay in school for an extra year to take Advanced Highers.

- **Undergraduate qualifications.** The standard Scottish Honours degree programme takes 4 years, with an Ordinary (non-Honours or pass) degree qualification available after 3 years, and Integrated Masters (MMath) programmes taking 5 years. However there is some variety in this across the sector, with very highly qualified students eligible to be admitted directly into the second year of the degree programme in most institutions. There are also accelerated MMath degree courses, in which well-qualified students can study material up to MMath level over 4 years. Scottish university qualifications are governed by the Scottish Credit and Qualifications Framework (**www.scqf.org.uk**).

- **Undergraduate funding.** The Scottish Funding Council (SFC) full fees for UK/EU undergraduate mathematical sciences students are £5590 per year per student (up to a given number of students assigned to each institution). SFC pays only the tuition fee (£1820 per student pa) for the first 10% of UK/EU students above this institutional quota, and nothing for any more UK/EU students admitted. This "cap" on all UK/EU student numbers was introduced at short notice for 2010-11; previously STEM (science, technology, engineering, mathematics) student numbers were not capped. One key difference with England is that Scottish students themselves do not pay any tuition or "top-up" fees.

- **Research funding.** UK government funding of research is fairly complicated: the remit of the seven Research Councils is UK-wide, whereas each of the four constituent countries within the UK (England, Scotland, Wales and Northern Ireland) has its own separate Funding Council. These twin strands of funding comprise the <u>dual support system</u> for research, which is described at **www.rcuk.ac.uk** as follows: *Under the dual support system, the Research Councils provide grants for specific projects and programmes, while the UK's Funding Councils provide block grant funding to support the research infrastructure and enable institutions to undertake ground-breaking research of their choosing*.

  The SFC's research funding methodology changed substantially in 2009/10, and is now very different from the two-stage process used by HEFCE in England. There is a change in nomenclature to reflect the change in methodology: Scottish research funding is now called the Research Excellence Grant (REG) instead of QR, and is calculated from a single formula. The key difference from England is that the size of the "discipline pot" in Scotland depends heavily on the number of research associates, research students and grant income. This penalises grant-poor subjects like the mathematical sciences and led to a 22% cut in funding in Scottish mathematical sciences in 2009/10 compared to 2008/09, despite an excellent RAE performance and a large increase in academic staff submitted. Scottish mathematical sciences research funding is further penalised compared to that in England because SFC uses substantially lower "cost weights'" in the funding formulae for Applied Mathematics and Statistics & Operational Research than those used by England.