NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC Radioactivity & the Environment (RATE) Programme: Expert Group recommendations for Science Priorities and Capacity Needs

Compiled by: RATE Secretariat

Foreword

NERC is commissioning an £8m, five-year research programme - Radioactivity & the Environment (RATE) – focused on capacity-building, with projects planned to run between 2013-14 and 2017-18. It will form part of the NERC contribution to the wider RCUK Energy Programme and falls under NERC's Environment, Pollution & Human Health (EPHH) strategic theme.

NERC established an Expert Group (EG) to help re-scope the RATE action to ensure that the programme develops capacity to secure future UK capability in the field of radioactivity and the environment. The EG included representatives from a number of relevant disciplines including radioecology, environmental radioactivity, hydrochemistry, hydrogeology, radionuclide transport, geomicrobiology and radioactive waste disposal.

This report prepared by the RATE secretariat and based on the deliberations of that EG, contains their validated recommendations on the scope and proposed activities to be included in the research programme. This report contains:

- Recommendations about the priority research areas, building on previous scoping work (in particular the 2009 Pentreath report and 2010 Harrison Theme Action Plan (TAP) proposal). Consideration of radioactivity in the marine environment will also be included;
- Recommendations about types of activity to include in the research programme to attract researchers with the required and novel expertise, including the potential capacity to be drawn in from related research disciplines;
- Recommendations about elements to include in the research programme to deliver the priority areas (*e.g.* for research, coordination, management, training and impact), and;
- Recommendations about where capacity will be needed to address identified priority research areas.

Acknowledgements

The secretariat would like to thank all of the attendees at the 1st RATE EG meeting held in May 2012 for their valuable participation and contribution to the meeting at which the recommendations were developed.

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Executive Summary

This report describes the process that the EG underwent, at a two day meeting, to develop the recommendations for the refocusing of the RATE programme. The recommendations presented in this report represent the consensus view of the EG. The recommendations are divided into two sections, Science Priorities and Capacity Needs.

The high priority science area recommendations are:

- Improved knowledge of (bio)geochemical coupling including multiphase transport processes;
- Technological innovation for rock mass characterisation at a range of spatial scales;
- Learning from natural radioactive analogues and man-made contaminated environments (natural laboratories) to underpin models and assessments;
- Innovative approaches to ecosystem/food chain radionuclide uptake processes for key radionuclides relevant to waste disposal facilities and contaminated land;
- Improved understanding of effects of chronic exposure on plants and animals, and;
- As a cross-cutting theme: enhanced capabilities in model testing, scientific demonstration of robustness, and quantification of uncertainty.

To address SISB's concerns regarding radioactivity and the marine environment, the EG specifically considered this issue. They noted that consideration of the 'marine environment' is important and, that projects in this area should fall within the science priority areas listed above.

The recommendations of the EG for building capacity, in response to SISB are:

- Involvement of PhD studentships in multidisciplinary projects;
- Development of a potential long-term career path;
- Sustainability of funding to help retention within the sector;
- Geosciences (including geochemistry, geology, geophysics, geomicrobiology), because of strong competition with other industries and under capacity;
- Environmental radioactivity and radioecology (including radioanalytical skills, radiochemistry, field radioecology and modelling) because of significant under capacity;
- Participation in and creation of wide networks including non-academic organisations, and;
- The EG expect that RATE will create a group/network that will have a much greater longevity than the RATE project itself.

The overwhelming consensus of the EG was that RATE should consist of two large consortium projects over 4 years with a number of PhD studentships associated with each consortium. In addition, a number of other factors were identified as important to the successful delivery of RATE including:

- That there should be an annual meeting for the whole of RATE that should be open to other interested parties, and;
- That the students should have regular opportunities that will encourage integration between the consortia and knowledge exchange between participants, *e.g.* summer school/training events.

1 Introduction

There are many important reasons to expand UK research on radioactivity in the environment. For example, in response to tough targets for reduction of greenhouse gas emissions, it is possible that a new generation of nuclear power plants may be commissioned in the UK and elsewhere. The UK faces significant legacy issues associated with radioactive waste and contaminated sites; and there has been a recent change in paradigm for environmental protection from radiation.

To address this, NERC is commissioning an £8m, five-year research programme - Radioactivity & the Environment (RATE) – focused on capacity-building, with projects planned to run between 2013-14 and 2017-18. It will form part of the NERC contribution to the wider RCUK Energy Programme and falls under NERC's Environment, Pollution & Human Health (EPHH) strategic theme. Financial support for the programme is from NERC (£5M), the Nuclear Decommissioning Authority – Radioactive Waste Management Directorate (NDA-RWMD) (£2M) and the Environment Agency (EA) (£1M).

To ensure that RATE addresses relevant areas of research, which are currently underrepresented in the UK, while building capacity in the field, NERC appointed an Expert Group (EG) to advise them on key areas in which the resources available to RATE should be focussed.

2 Background

NERC has been considering a research programme on this topic and in 2009 commissioned Jan Pentreath to provide advice to them on the UK's research needs over the next 10 years. In September 2010 Roy Harrison, the Theme Leader for EPHH, held a meeting to discuss a potential NERC proposal for an action on Radioactivity and the Environment. This meeting report was used to develop the TAP Action which has been approved by SISB and NERC council, with some changes, as detailed in the SISB feedback. This defines the boundaries and scope discussed at the EG meeting.

Evidence provided to the EG for their consideration:

- NERC Report (Pentreath);
- Radioactivity and the Environment meeting notes (CONFIDENTIAL);
- TAP Action;
- SISB response;
- Terms of Reference for membership of the Expert Group;
- Membership list of Expert Group;
- Provisional Programme;
- NERC policy on vested interest;
- House of Lords select committee report 'Setting priorities for publicly funded research', and;
- NDA CD on geological disposal.

3 Process

3.1 SELECTION OF EXPERT GROUP MEMBERS

NERC invited applications from individuals interested in joining a time-limited EG for RATE. The group was tasked to advise the NERC Programme Executive Board (PEB) on priority areas for research and ways to build UK research capacity in these areas. The British Geological Survey (BGS) provided the secretariat for the EG. The relationships between the PEB, the EG and the Secretariat is given in Figure 1. The EG will be disbanded following publication of this report to NERC.

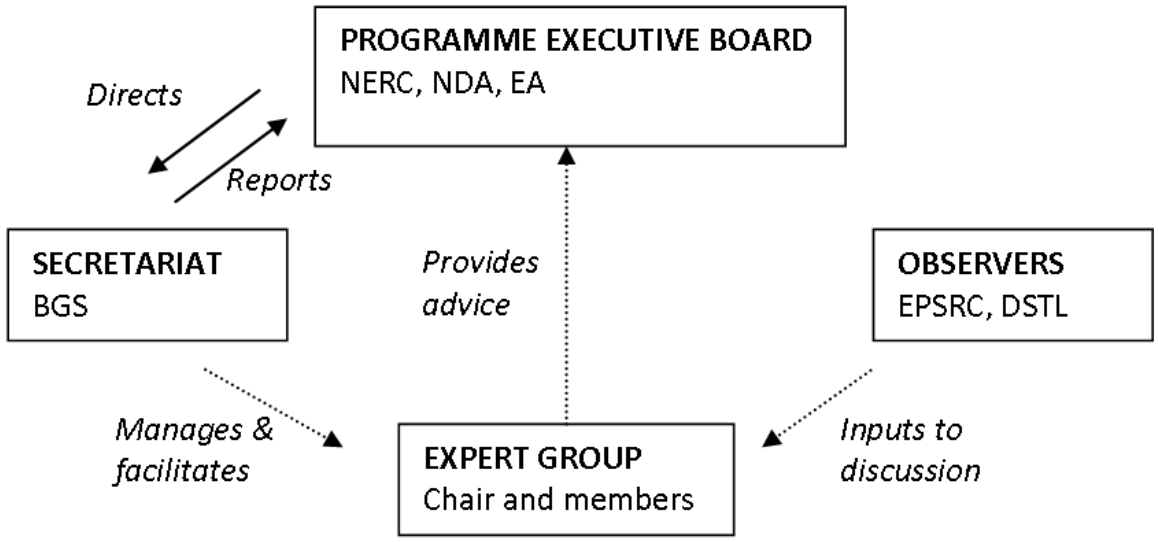

Figure 1 Programme bodies and their interaction within the RATE programme

Selection of EG membership was the responsibility of the RATE Programme Executive Board and appointed members to achieve a balanced representation. EG membership included representation of the following groups:

- The UK and international academic community;
- Relevant government departments and policy-makers, and;
- End users, including industry and business experts.

Professor Mike Kendall of Bristol University was invited by NERC to chair the EG.

The EG members were:

- Mrs Joanne Brown - Centre for Radiation, Chemical and Environmental Hazards Health Protection Agency (HPA);
- Professor Neil Chapman - MCM International;
- Dr Brenda Howard MBE - Centre for Ecology & Hydrology (CEH), Lancaster Environment Centre;
- Professor Paul Leonard - Corporate Risk Associates Ltd;
- Professor Francis Livens - Dalton Nuclear Institute, University of Manchester;

- Professor Jon Lloyd - School of Earth, Atmospheric and Environmental Sciences, University of Manchester;
- Professor Becky Lunn - Department of Civil & Environmental Engineering, University of Strathclyde;
- Professor Angus MacKenzie - Scottish Universities Environmental Research Centre;
- Professor Marian Scott - School of Mathematics and Statistics, University of Glasgow, and;
- Professor Jim Smith - School of Earth and Environmental Sciences, University of Portsmouth.

Members of the PEB who attended and contributed to the EG meeting were:

- Dr Chris Franklin – NERC;
- Dr Caroline Culshaw – NERC;
- Dr Jon Martin – NDA;
- Mr Andy Mayall – EA, and;
- Dr Neil Smart – NDA.

NERC Theme Leader EPHH:

- Professor Roy Harrison.

Observers (OBS) who attended and contributed to the EG meeting were:

- Mr Mike Gooding - DSTL Porton Down.

The Secretariat, from the British Geological Survey (BGS), were:

- Dr Richard Shaw;
- Dr Jenny Bearcock, and;
- Dr Joanna Wragg.

The interests and expertise of members of the EG, PEB and observers is given in the detailed summary of the EG meeting in Annex 1 of this report.

3.2 EXPERT GROUP MEETING

The EG attended a two day meeting held at BGS Keyworth offices on 2nd and 3rd May 2012. The format of the meeting, agreed between the secretariat and NERC was designed to elicit a consensus from the EG within the boundaries set by the three bodies which are contributing to the funding of RATE.

A detailed summary of the meeting is provided as Annex 1 to this report.

3.3 OPPORTUNITY TO COMMENT

Following completion of the EG final draft report it was made available to allow any interested individuals or organisations to comment on the draft recommendations. This was undertaken using a web-based approach accessible from the RATE pages on the NERC web site. The comments received were collated into a single document together with suggested revisions to the recommendations to NERC that the RATE Secretariat thought appropriate in the light of the comments. This document was circulated to the EG for their consideration and their comments compiled. The RATE Secretariat has revised the recommendations to NERC taking into consideration the responses received from the EG. A summary table is provided as Annex 2 compiling all comments, responses and revisions made.

4 Recommendations

Based on the outcomes of the EG meeting the recommendations from the EG to the PEB are given under the four headings below.

4.1 SCIENTIFIC SCOPE AND PRIORITIES FOR THE RATE RESEARCH PROGRAMME

Table 1 Science priorities (high)

Priority	Justification
(Bio)geochemical coupling including deep multiphase transport processes - hydro-(bio)geochemical reactions under GDF conditions - gas production, consumption, reactions and transport especially methane and hydrogen - Coupled THMC processes - fluid movement and radionuclide transport including long timescales - microbial ecology and radiation microbiology of a GDF	Highlight areas of scientific uncertainty where significant progress could be made due to new investigative techniques and tools Focus on radionuclides of particular concern in the UK context
Technological innovation for rock mass characterisation at a range of spatial scales - including technology transfer from other industrial/research sectors - emphasising the 1-100m scale - far-field near-field interface, including fractures and faults	This is timely for the programme. Site investigation will occur in *ca.* 2015 to 2018. Research is needed to deploy scientific advances and modern technologies that have been developed for other applications.
Learning from contaminated environments including natural analogues (natural laboratories) - including natural analogues for the long-term preservation of potential repository materials, such as bentonite clay, copper, *etc* (i.e. as a complement to the suggested natural radioactive analogues	Provides fundamental underpinning of understanding, model testing and parameterisation in real environmental systems. Applicable to remediation, waste disposal and nuclear power generation impact assessments. Natural Laboratories include both marine and terrestrial environments *e.g.* as a result of accidents such as Fukushima and Chernobyl, natural contamination *e.g.* Uranium mineralisation or contamination as a result of normal operation *e.g*. Irish Sea *etc*.
Innovative approaches to ecosystem/food chain radionuclide uptake and transport processes for key radionuclides relevant to waste disposal facilities and contaminated land	Reducing uncertainty in transfer parameter values on the basis of key radionuclides and environmental variables (such as soil/sediment type) and incorporating spatial and temporal variability. Assessment models are highly sensitive to reported Kd and CR values, which exhibit great environmental variability of which we don't yet have a fundamental understanding.
Effects of chronic exposure on plants and animals	Improved understanding of the level of dose causing significant negative impacts on plants and animals. Derivation of suitable benchmark/reference levels. The current scientific basis needs to be strengthened for chronic exposure (with gaps in knowledge and fundamental data).
Cross-cutting theme: model building/testing, demonstration of scientific robustness, and quantification of uncertainty	Proposals which recognise the cross-cutting theme of model building, testing, robustness, reduction/quantification of uncertainty and innovative ways of presenting models to a wide

	audience will be viewed positively

Table 2 Science priorities (lower)

Priority	Justification
Climate change	Where relevant, there is a need to capture change in environmental boundary conditions as a result of climate change in the high priorities
Background radiation	Doses to the public vary widely across the world. The way that the public are exposed and the potential detriment need further study + explaining in terms of comparative risk
Wildlife dosimetry (see Appendix 1)	Exposure of wildlife has been the subject of recent ICRP publications and more work could be undertaken *e.g.* sensitivity of organisms during their life – cycle.

Tables 1 and 2 identify those areas that the EG believe would benefit from investment under RATE. It was specifically noted that while 'marine' is covered by the call, specific topics in this area have not been recommended as areas with high science priority and thus 'marine' ecosystems do not require extra emphasis over any other topic, but should be encompassed in the overall scope of projects developed under the future RATE call.

4.2 CAPACITY NEEDS TO DELIVER RATE

To achieve its long term goals, the consensus of the EG is that RATE needs to include the:

- Involvement of PhD studentships in multidisciplinary projects;
- Development of potential long-term career path;
- Sustainability of funding to help retention within the sector;
- Geosciences (including geochemistry, geology, geophysics, geomicrobiology, climate), because of strong competition with other industries and under capacity;
- Environmental radioactivity and radioecology (including radioanalytical skills, radiochemistry, field radioecology and modelling) because of significant under capacity, and;
- Participation in and creation of wide networks including non-academic organisations.

RATE needs to attract multidisciplinary scientists with experimental knowledge/ breadth with both field and laboratory skills, foster cross industry participation, skills transfer and training of people from other fields. It should also facilitate access to underground research laboratories (URLs), 'active' and other research facilities.

4.3 MECHANISMS TO ATTRACT, DEVELOP AND MAINTAIN THE REQUIRED CAPACITY

To encourage researchers from other sectors to be involved in RATE, it needs to present exciting science opportunities in an important area of science that will contribute to managing our nuclear legacy safely and to help facilitate a sustainable low carbon energy mix in the future. It should emphasise the potential for young scientists in Britain, where a new important science challenge is arising, for which we need to develop future innovative leaders to work together to address these topics within their careers.

The EG expect that RATE will evolve into a group/network that will have a much greater longevity than the RATE project itself.

The EG considered that the audience for the programme should not be limited to the academic and specialist community; there is a need for effective wider communication of the programme and its outcomes to help build public confidence in the UK's research capability in this area. Public engagement is now a vital element in taking forward the UK's legacy and new build programmes. The EG thought that it is beyond the scope of RATE to fund specific communication projects/tasks but that effective communication should be an integral part of all projects - a cross-cutting theme.

4.4 POTENTIAL FUNDING MECHANISMS TO DELIVER RATE

The EG considered whether funds should be distributed to fund two large consortia or a greater number of smaller consortia. The overwhelming consensus was for RATE to consist of two large multidisciplinary consortium projects over 4 years with a number of PhD studentships included in each consortia. In addition a number of other factors were identified as important to the successful delivery of RATE including:

- That studentships should be embedded into the multidisciplinary consortia, although the students could be based at associated institutions;
- That there should be an annual meeting for the whole of RATE that should be open to other interested parties;
- That the co-ordination of RATE should have strong links with COGER (and similar groups) to facilitate good external communication and outreach;
- That there are no special requirements for data management (other than NERC requirements), and;
- That the students should have regular summer schools/training events that will encourage integration between the consortia and knowledge exchange between participants.

Several cross-cutting requirements/approaches were identified (*e.g.* model validation and uncertainty, innovation in presenting model outcomes and their meaning, consideration of, environmental/climate change), which should be an integral part of RATE.

The funding available for RATE is relatively modest and the EG suggests that it should not be directed towards major infrastructure investment within the programme and that as much use as possible should be made of existing national and international facilities where appropriate.

Glossary

'Active' – some degree of special handling is required for the radioactivity *e.g.* glove boxes

APTS – Academy for PhD Training in Statistics

AWE – Atomic Weapons Establishment

BBSRC – Biotechnology and Biological Sciences Research Council

BGS – British Geological Survey

CMIPs – Common Management Information Protocols

COGER – Co-ordinating Group for Environmental Radioactivity

CoRWM – The Committee on Radioactive Waste Management

CR – Chemical Reactivity

CREAM – Consequences of Rereleases to the Environment: Assessment Methodology. A modelling methodology for evaluating the radiological consequences of controlled releases

CROM – Código de cRiba para evaluaciÓn de iMpacto (Screening Model for Environmental Assessment)

DCRL – Distributed Computing Research Laboratory

DoReMi - A European Network of Excellence set up to address the health risks of low doses of ionising radiation

DSTL – Defence Science and Technology Laboratory

DTC – Doctoral Training Centre

DTP – Doctoral Training Programme

DTN – Doctoral Training Network

DU – Depleted Uranium

EA – Environment Agency

EDZ – Excavation Disturbed/Damaged Zone

EG – Expert Group

EM – Environmental Monitoring

EMRAS – Environmental Modelling for Radiation Safety

EPHH – Environment, Pollution and Human Health

EPSRC – Engineering and Physical Sciences Research Council

ERICA Tool - A software programme for integrated exposure/dose/effect assessment with risk characterisation and managerial considerations

ERT – Electrical Resistivity Tomography

ESRC – Economic and Social Research Council

EU – European Union

EurAtom – European Atomic Energy Community

FDP - Funded Decommissioning Programme

FP7 – European Union Seventh Framework Programme

GD – Geological Disposal

GDF– Geological Disposal Facility

GPR – Ground Penetrating Radar

'Hot particle' – a small, highly radioactive object, with significant content of radionuclides. More accurately termed High Activity Concentration Particle.

HPA – Health Protection Agency

IAEA SRS – International Atomic Energy Agency Safety Report Series

ICRP – International Commission on Radiological Protection

IRAT - Initial Radiological Assessment Tool

Kd – Partition coefficient

LLWR – Low Level Waste Repository

MIPs - Management Information Protocols

MOD – Ministry of Defence

MRC – Medical Research Council

NERC – Natural Environment Research Council

NDA-RWMD – Nuclear Decommissioning Authority Radioactive Waste Management Division

NHM – Natural History Museum

NORM – Naturally Occurring Radioactive Materials

NNL – National Nuclear Laboratory

NP – Nuclear Power

NPL – National Physical Laboratory

NSAN – National Skills Academy for Nuclear

OBS - Observer

ONR – Office for Nuclear Regulation

PA – Performance Assessment

PDRA – Postdoctoral Research Associate

PEB – Programme Executive Board

PGP – Post-Genomics & Proteomics (www.nerc.ac.uk/research/programmes/proteomics/)

PI – Principal Investigator

RATE – Radioactivity and the Environment

RAP – Representative Animals and Plants

RCUK – Research Councils UK

SEPA – Scottish Environment Protection Agency

SISB – Science & Innovation Strategy Board

SMSTC – Scottish Mathematical Sciences Training Centre

STAR – Science, Technology and Research network

STFC – Science & Technologies Facilities Council

SUERC – Scottish Universities Environmental Research Centre

TAP – Theme Action Plan

THMC – Thermal – Hydro – Mechanical - Chemical

UKAEA – United Kingdom Atomic Energy Authority

URL – Underground Research Laboratory

Annex 1

Summary of 1st Expert Group Meeting for the NERC RATE Project – 2nd/3rd May 2012

Day 1:

Introduction and Overview

Introduction – Mike Kendall:

Mike Kendall (MK, University of Bristol), Chair of the RATE panel welcomed the panel to the meeting and introduced himself to the Expert Group (EG). MK explained his background and noted that he was not an expert in the area under discussion but applies the science to his particular field, resulting in him being an impartial chair and able to guide the process. MK further explained the goal of the project and the meeting, stating that the focus was on cutting edge and key research, making up for time lost in the recent past.

Housekeeping - Richard Shaw:

Richard Shaw (RS, BGS) informed the EG that the meeting had been convened to begin to re-scope and organise the NERC RATE programme, with BGS in the secretariat role. RS stated that he was leading the secretariat and that he was supported in this role by Joanna Wragg (JW, BGS) and Jenny Bearcock (JB, BGS). RS informed the EG that in order to stay independent, he would not bid into the final RATE programme, however, BGS was still eligible to do so. RS took the EG through the BGS 'housekeeping' requirements for fire alarms, refreshments and the social and travel arrangements for the meeting.

Agenda

Day 1	**Wednesday May 2nd 2012**
10:15	Coffee and welcome
10:45	Chairman's welcome – Mike Kendall
11:00	Round the table introductions
11:20 – 13:00	Scene setting – Richard Shaw, Roy Harrison, NDA and EA
13:00 – 14:00	Lunch. Over lunch there will be an opportunity to take advantage of the BGS facilities and take a tour of the new geological garden (weather permitting) or the 3D visualisation suite.
14:00 – 15:30	Priority science areas discussion session
15:30 – 16:00	Afternoon coffee
16:00 – 17:30	Capacity needs discussion session
17:30	Day 1 wrap up, including provision of information on transportation and hospitality arrangements

Day 2	**Thursday May 3rd 2012**
09:00	Recap of Day 1 – Richard Shaw
09:30	Science priorities break out discussions
10:30	Coffee
11:00	Capacity needs break out discussions
12:30	Lunch
13:30	Feedback from breakout sessions
14:30	Development of recommendations
15:30	Meeting summary – Caroline Culshaw
15:35	Wrap-up and next steps – Richard Shaw
15:55	Chairman's closing remarks - Mike Kendall

Introductions

RS kicked off the 'round the table' introductions of the EG, the Programme Executive Board (PEB) and the observers present:

- Richard Shaw (RS), BGS (secretariat) - senior scientist working in radioactive waste for over 20 years and has a background as a mining geologist
- Chris Franklin (CF), NERC (PEB) – Has 3 roles: Science & Innovation officer - responsible for earth science and science based technology; supports Theme Leaders – putting together action plans, delivering strategic research programmes; delivers cross research council science as the energy representative.
- Joanne Brown (JB), Centre for Radiation Chemical and Environmental Hazards, HPA (EG) - Runs the environmental investigations group for radiation, which includes the radiochemistry laboratories. Responsible for radioactive contaminated land and provides advice from the HPA. The group carries out site specific assessments, experimental studies to support food chain modelling and countermeasures advice amongst its portfolio.
- Jim Smith (JS), Portsmouth University (EG) – Has worked in radio-ecology for ~20years. Is a mathematical modeller and has studied the transport of radionuclides from Chernobyl and their effect on organisms in the Chernobyl exclusion zone.
- Becky Lunn (BL), Strathclyde University (EG) – Professor of Civil Engineering, works in areas which include geodisposal and groundwater engineering. Has a joint research group with Glasgow University. Is leading two EPSRC consortia in cross cutting programme – microbial grouting systems and monitoring clays that surround high level wastes. Present at the EG meeting in a geology capacity. Committee member of the Committee on Radioactive Waste Management (CoRWM).

- Jon Martin (JM), NDA (PEB) –~20 years' experience in the radioactive waste industry as a radiochemist, 15 with Magnox, several with UKAEA, two with Energy solutions and is currently head of research at the NDA.
- Neil Smart (NS), NDA (PEB) –22 years in industry, 7 of those with the NDA.
- Caroline Culshaw (CC), NERC (PEB) - Programmes officer, planning delivering research programmes in the Environmental Pollution and Human Health theme. Managing process of this meeting for NERC and managing the programme until May.
- Andy Mayall (AM), EA (PEB) – Has 24 years' experience in this field: this includes work with the HPA on health effects, radiological assessment and environmental modelling and in the past 15 years as a nuclear regulator (principally at Sellafield) for the EA; experience also includes advisory work in the new build sector. EA representative on the ONR team Fukushima lessons learned report team, and is currently on secondment to the Office for Nuclear Development at the Department of Energy and Climate Change.
- Marian Scott (MS), University of Glasgow (EG) –Has worked in the area of the use of radioactive tracers for environmental process understanding and also for chronology development. This had led to research on impact assessment in the case of disposal of nuclear submarines in the sea (Kara Sea, IAEA Arctic programme) *etc*. Understanding and modelling risk and uncertainty quantification research priorities.
- Mike Gooding (MG), DSTL (OBS) – A background in providing consultation expertise on decommissioning and has worked for the MoD for 20 years. Leads on environmental radioactivity programmes and has a keen interest in environmental radioactivity.
- Brenda Howard MBE (BH), CEH (EG) – 30 years' experience as a radioecologist in the terrestrial environment, investigates the transfer of radioactivity to ruminants and emergency response and remediation, environmental protection and transfer of radioactivity to wildlife. Substantial experience as a co-ordinator of large European projects.
- Paul Leonard (PL), Corporate Risk Associates Ltd (EG) – Has worked on a large variety of projects and with many collaborators including Jan Pentreath and on Chernobyl. He has experience as a nuclear inspector and advises ministers. He is involved with knowledge exchange projects and has a background in emergency response, communication to the public and risk communication.
- Roy Harrison (RH), University of Birmingham/NERC (EPHH theme leader) – On secondment with NERC as Theme Leader for Environmental Pollution and Human Health and originally brought the RATE programme to NERC council for consideration and approval.
- Neil Chapman (NC), MCM International (EG) – Has worked in radioactive waste management since 1970s. Has been/is involved all UK programmes on geological waste management from site characterisation to safety and

supporting safety cases - anything to do with geological disposal. Is interested in natural analogues. Has been a consultant since 1990, based in Switzerland. Works part time at Sheffield University and is the Chairman of the radioactive waste management directorate.

- Gus Mackenizie (GM), Scottish Universities Environmental Research Centre (SUERC) (EG) – Interested in radiobiogeochemistry, radionuclide tracer studies and has 40 years' experience in the field.
- Francis Livens (FL), Manchester University (EG) – Chemist by training, works as a radiochemist. In his own words 'a Plutonium obsessive'. Sits on advisory boards such as COGER/CoRWM and is interested in both natural and engineered systems. Principal investigator (PI) on the Manchester/Sheffield Nuclear Fission Doctoral Training Centre funded by EPSRC.
- Jon Lloyd (JL), Manchester University (EG) – Heads up the Geo-microbiology group, is involved with the new centre for radioactive waste. Has 20 years' experience in 'microbial interactions with radionuclides' and is 18 months into a 4 year secondment with the National Nuclear Laboratory (NNL) to build a "nuclear microbiology" programme using Manchester/NNL/industrial infrastructure.

Scene Setting

- RS introduced the section of the meeting to set the background and purpose of the meeting (summarised in Table 1);
- CF provided an overview on behalf of Research Councils UK (RCUK);
- RH provided the EG with the time line of events leading up to the re-scoping of the RATE project and the reduced budget of £5M, the reasons for convening the EG;
- Members of the PEB (NS and JM from the NDA and AM from the EA) detailed their interest in the programme, given that their organisations were providing an additional £2M and £1M to the overall budget respectively, and;
- Finally, MG from DSTL provided input as one of the project observers.

This section of the meeting not only set the background reasons for the EG meeting, but also started to inform the EG of the boundaries within which the re-scoping exercise should remain.

Table 1: Summary of scene setting presentations

Presenter	Summary	Questions
Chris Franklin	The NERC perspective with some information on EPSRC. NERC's view of energy is from an environmental perspective. RATE is linked to the RCUK Energy programme and 5 programmes fund Energy. Nuclear has 7% of the current total funding of £725M. The Energy programme has a nuclear champion, which the EG should make use of. The EG should think about how to link EPSRC/NDA and STFC networks together. ESRC interest could be about how the voluntary selection fits/works in the UK timescales, intergenerational aspects. EPSRC/ESRC joint call on critical infrastructure.	Q: Is there an interface between BBSRC and the nuclear area? A: There doesn't seem to be, they don't talk much about the nuclear side, but there should be. Any missing links can be addressed. Q: ESRC are more interested, has there been a change of mind? A: Geological disposal unique in UK, understanding how you make voluntarism work is important. Fiddling with dialogue is missing the point. Q: What's your feeling Chris about how close the interfaces are between research councils A: Very strong
Roy Harrison	Background information on the history of the RATE programme. RATE falls into the Environmental Pollution and Human Health (EPHH) NERC theme, but there are overlaps with other themes. Highlighted the marine issue – that SISB felt marine was not represented. Pointed out that directed or responsive and international links are still to be answered. Highlighted going back to SISB for more money.	Q: Non- human biota? Is this now clearly within scope? A: Yes Comment: Effects on humans is MRC or other councils but dosimetry could be included. Q: Who is looking at lower dose effect?

	Said that we can learn from human work on low doses (there is lots of work already going on – DoReMe in EurAtom). Characterisation and evaluation of environmental change over 1M yrs seems peripheral to radioactivity? Can be considered under the broad remit of RATE.	A: Probably no-one Q: Should we not include it? A: It is out of our remit. Comments: NERC are talking to the Department of Health. There is not a lack of funding in that area.
Neil Smart and Jon Martin	Introduction to the roles and responsibilities of the NDA, defining the boundary conditions of its involvement in RATE with respect to its contribution of £2M of funding. Told the group that this deal was yet to be signed, but expectation is that they will be on board. Informed the EG that the NDA can only fund work within the scope of their remit *i.e.* not new build, but research related to geological disposal. Stated that the NDA relationship with EPSRC was a really good model. The NDA could define the boundaries of the research, but let the EPSRC fulfil their remit on the quality of science. Fundamental science and particular problems can be targeted. Stakeholder engagement, transparency and openness are important. Want to influence joint initiatives. Success factors of broad alignment, technical transfer from non-nuclear applications, collaborative	Q: Have the NDA thought about very deep boreholes, is it in the remit? A: They maintain an awareness of international developments in deep borehole disposal but not fund any work in this area. Comment: The US is funding this and we could piggy back onto it.

	interdisciplinary teams, capacity building, and value for money. Have carried out some work already on impact of GDF on different types of rock, but need to keep generic because don't know the sites. Can start site investigations when there is engagement from a volunteer community (should know in the next few months). Have very clear research needs and identified which ones would be in scope for this collaboration.	
Andy Mayall	EA remit is protection of people and environment, and the regulation of radioactive waste disposal from the nuclear and non-nuclear industry. EA works closely with the Office for Nuclear Regulation (ONR). EA's priorities are to ensure that the infrastructure is in place for legacy decommissioning and clean-up, and radioactive waste management and disposal; and to ensure that new nuclear power stations meet world class environmental standards. There is a focus on hazard and risk reduction, use of an effective waste management hierarchy and obtaining good evidence for its regulatory framework and decisions Key drivers for what it would like to see in the RATE programme include the increased emphasis on environmental radiological protection, filling gaps in data for ref animals and plants and providing a robust evidence base for its regulatory decisions including on GDF. EA have made SEPA and Northern Ireland EA aware	Q: Are post-accident/ emergency models in your remit? A: It's not strictly part of our permitting remit for nuclear licensed sites– it is an ONR issue as part of accident consequence assessments performed as part of the site licensing framework. However, we do have a strong interest in it because accidents will have environmental impacts, require post-accident clean-up and generate waste for disposal, and advise and work with ONR and others such as HPA on this issue. Comment: Climate scientists have done a lot of work collaborating to improve models, their uncertainty – and communicating this uncertainty to the public. Our community needs to do the same. A: agreed – there needs to be a rethink about how radiological assessment model results are presented to a wider audience *e.g.* perhaps probabilistically or by use of ensembles of model results.

	of the involvement with RATE, taken their comments into account, but are not speaking on their behalf. EA works with other bodies, such as nuclear industry to carry out R&D and scrutinises R&D as the regulator. Government expects the EA to publish R&D. Solid radioactive waste is a very important area, *e.g.* the EA will be the regulator for permitting borehole investigations and eventual disposals at the GDF. Research is needed to update models to ensure they are fit for purpose, as they are coming under ever greater public scrutiny. There is scope for work on radionuclide behaviour in disposal environments in response to: temperature, ionic strength, microorganisms, and organic complexation. Much of the work is currently at standard temperature, in abiotic systems. Need to improve understanding in speciation in different redox environments, production and migration of gases, and long-term geosphere stability. The outputs of RATE need to lead to applied outcomes.	Comment: if we want to do MIPs, we should look to CMIP *etc*. to understand model uncertainty. There is a good network of sensors in Fukushima, reporting levels very frequently – there is an opportunity to utilise this. There is nothing on a similar scale in the UK.
Mike Gooding	Interests in deterrent (nuclear weapons – dealt with by Atomic Weapons Establishment (AWE), own legacy issues, assurance requirements for test sites). DSTL is conduit for defence-related research – has a knowledge-integrator role, but does a bit of research. **Research interests** • Nuclear propulsion – MOD still building nuclear	

	reactors for submarines that need waste-management disposal. • Environmental impact of submarines and operations – effects of submarines on environment and people. • Nuclear accident response – *e.g.* detection of radionuclides in marine environment. • Protecting their personnel from CBRN. • Detection of nuclear smuggling into country, remote alpha emitter detection, and associated new direct and indirect techniques. • Potential integration of existing technologies with new platforms. • Threats to national infrastructure (monitoring for radiological attack). • Other legacy issues – historic use of radium as a luminising agent. • Transport of radionuclides from historic sites. • Sampling and analysis – *e.g.* of DU firing ranges. What is a representative sample, to what extent is a hot particle related to dose? • Continued interest in transport of radionuclide in the environment, and radionuclides as tracers. Was interested in DU, not a focus for them anymore but continues to be an issue as long as used in munitions. DSTL are present as an observer, but are very interested in the outputs and have a vested interest.	

CF reminded the group that they had just been presented with the boundaries from the three funding bodies within which to focus the re-scoping exercise.

Roles of Individuals/Groups

RS described the programme bodies, and how they were going to interact within the RATE programme (Figure 1).

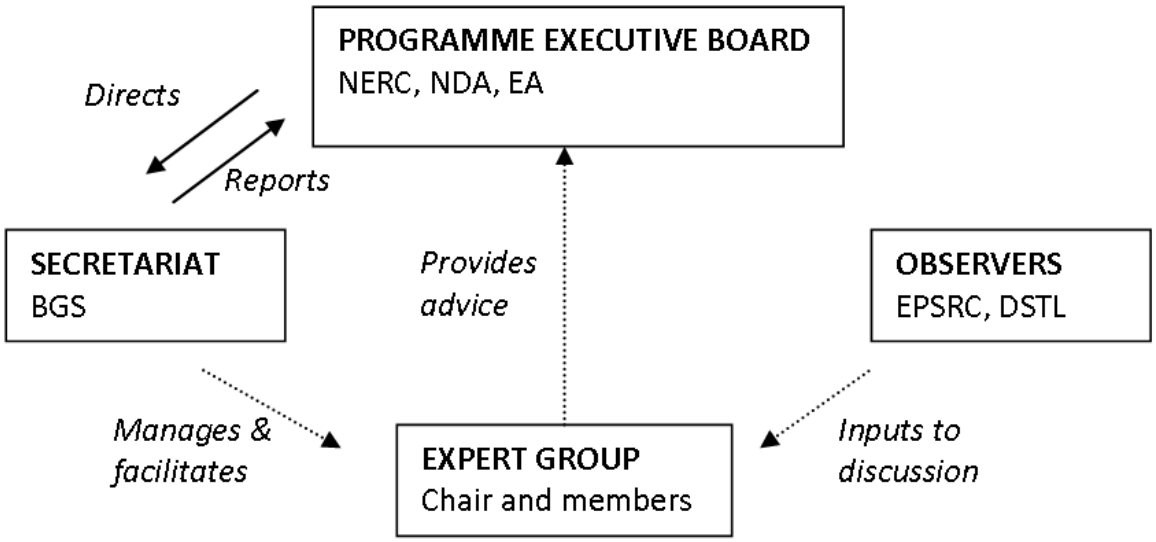

Figure 1: Programme bodies and their interaction within the RATE programme

The PEB is responsible for:

- Strategic direction and delivery of the Programme;
- Financial management;
- Taking advice from the Expert Group, via its Chair, and;
- Directing the Secretariat.

The roles of the Secretariat were listed as:

- Reporting to the PEB;
- Implementing the decisions of the PEB;
- Managing the EG and related process;
- Ensuring the EG delivers a high quality and fit-for-purpose report, and;
- Delivering the EG report to the PEB.

The EG were facilitated and managed by the Secretariat and were required to:

- Provide advice, via its Chair, to the PEB;
- Invited to represent a range of viewpoints from different disciplines and types of organisation as experts in their own right;
- Produce a report containing the recommendations below, and;
- Provide the PEB with recommendations on:

- Scientific scope and priorities for the RATE research programme;
- Capacity needs to deliver RATE;
- Mechanisms to attract, develop and maintain the required capacity, and;
- Potential funding mechanisms to deliver RATE.

The Observers were:

- Present at the discretion of the PEB;
- Responsible for providing the EG with information on their organisation's activities and interests, and;
- Expected to participate fully in EG discussions to ensure that recommendations were informed by on-going activities and opportunities for partnership.

Purpose of the meeting

RS explained to the group that the purpose of the meeting was to re-scope the NERC Radioactivity and the Environment (RATE) action to focus the Programme on building capacity in the field. Within this the secretariat would be responsible for producing a report based on the deliberation of the EG containing validated recommendations on scope and activities to include in a research programme (£5M from NERC + £3M from NDA/EA) that will attract capacity to the field of radioactivity and the environment.

The focus of the meeting was to identify priority research questions and science topic areas for a new Programme, and for the EG to discuss and develop a series of draft recommendations over the two days.

RS stated that the outcome of the meeting would be specific preliminary recommendations which the Secretariat would formalise into a report to NERC. The draft report would be circulated to EG members for comment, and then there will be a web based 'opportunity to comment' before finalisation in September (with a second EG meeting if necessary).

Timeline of Events

RS summarised the following timeline of future events for the EG:

- Draft report to EG late May 2012 for comment;
- Finalise report early June 2012;
- Web based communication of report and feedback opportunity June- July 2012;
- Summarise feedback August 2012;
- E-mail (or physical if warranted) EG meeting to consider feedback 27 September 2012;
- Final report end September 2012, and;

- 'Town Meeting' 26th and 27th November 2012 – Natural History Museum (NHM) London.

Questions arising from RS overview

Q: What is meant by "capacity building"?

A: That will be discussed this afternoon; the priority is to decide on the science needs, and that is the reason for the meeting. The science needs will determine the capacity.

Science Priority Identification

JW outlined the process of identifying science priorities to the EG (PEB, OBS and RH were included in this process). To identify science priorities each member was asked to write his/her personal questions, ideas and topics to fulfil the RATE remit on individual post-it notes, identifying whether they were perceived as high, medium or low priority (Figure 2). Thirty minutes was allowed for this task.

Each member relayed their individual thoughts to the group, provoking discussion, facilitated by RS. Preliminary organisation into similar topics occurred as each member presented ideas to the rest of the group. As determining the key science priorities was the main focus of the meeting, discussion was allowed to continue beyond the 60 minutes which was originally envisaged for this task. The EG identified four groupings for further consideration: geosphere, biosphere, processes and pathways, and impacts.

Figure 2: Diagrammatic explanation of the science priority and capacity need task

Capacity Need Identification

The capacity needs were identified in a similar manner to the science priorities. The grouping of the capacity needs was more straightforward, and required less time, as

there was more replication across the EG. The EG identified three areas for further consideration: people, money, and facilities.

Evening meeting

After the meeting had closed, the PEB and secretariat met to restructure the programme for Day 2 in light of the extra emphasis devoted to the science priorities. Therefore further time was allocated to allow for clustering of the ideas put forward, prior to discussions of ranking of importance. It was felt that the science priorities took precedence over the capacity needs, and that collation of identified capacity needs could be undertaken by the secretariat followed by circulation to the EG for discussion. The structure for Day 2 was discussed and finalised. EG members were divided into two breakout groups for the prioritisation stage. Different champions were assigned to facilitate: a) the initial rationalisation exercise, b) the prioritisation of the science priorities, and c) the prioritisation of the capacity needs (if time permitted). Details of the allocation of EG members and champions are shown in Figures 3-5.

Day 2:

Introduction

RS welcomed the EG back, and introduced the programme of the day (see Figures 3-5).

Rationalisation of science ideas

The EG were asked to divide themselves into three sub groups to cluster similar ideas in order to rationalise the science priority ideas. Group 1 (champion JL) was assigned the ideas associated with the topics geosphere and biosphere. Group 2 (champion GM) was assigned the ideas associated with the processes and pathways topic. Group 3 (champion JS) was assigned the ideas associated with the impacts topic. The EG members who decided to address the topics in each group are shown in Table 2. CC and MG joined in with discussions in each group.

Table 2: Groups in which the science priority ideas were rationalised. The pre-appointed champion is highlighted in bold.

Group 1 (geosphere and biosphere)	**JL,** BL, MK
Group 2 (processes and pathways)	**GM**, FL, BH, JM
Group 3 (impacts)	**JS**, NC, PL, JB, AM, MS

The rationalisation process was allowed to continue for 30 minutes, prior to feedback presented to the whole group from each champion followed by group discussion. Any ideas that had been inappropriately assigned were redistributed at this stage. Each group reassigned topic headings to the general science priority under

discussion, and further provided sub headings where necessary. A transcript of the 'post-it' notes from the rationalisation process with these headings is shown in Appendix 1.

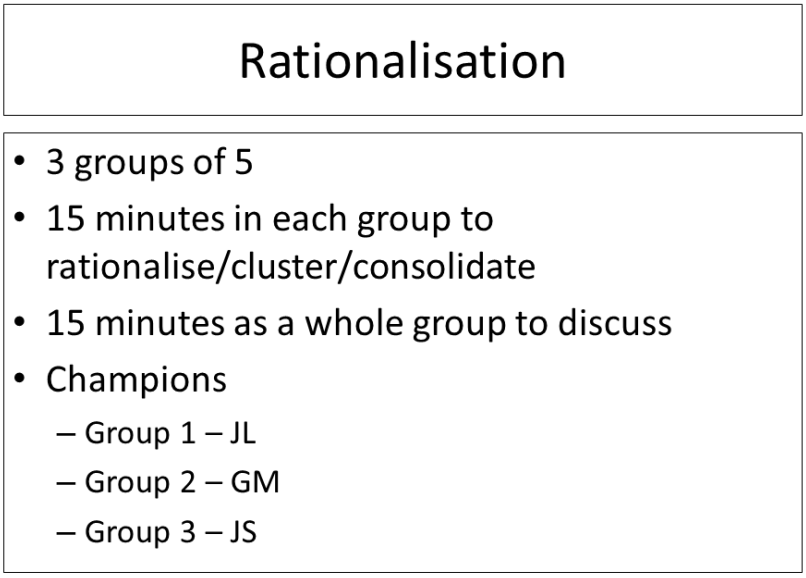

Figure 3: Slide outlining rationalisation exercise

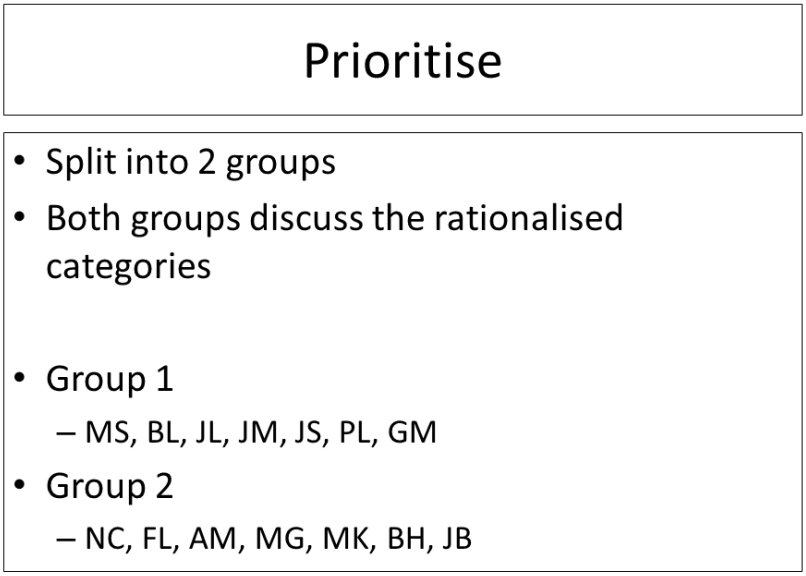

Figure 4: Slide outlining prioritisation exercise for both science priorities and capacity needs

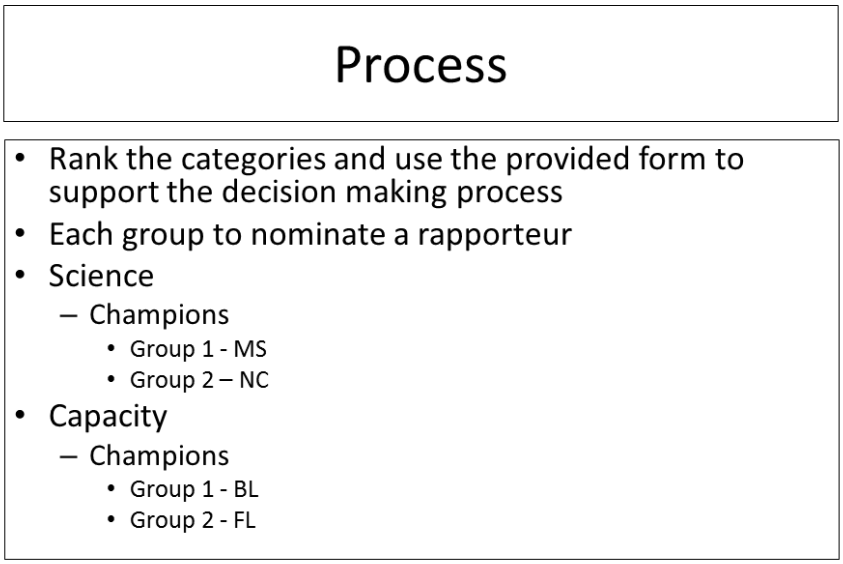

Figure 5: Side detailing the process of the prioritisation exercise

Prioritisation

The EG was split into two equal groups in order to facilitate prioritisation of the science ideas (Figure 4 and 5). The secretariat provided a written summary of the feedback presented to the group by each champion as a result of the rationalisation stage (Appendix 2). The two groups were asked to discuss, prioritise, and justify the identified science areas and provide written feedback.

The draft science priorities were presented to the whole group by each champion for further discussion, and initial refinement in a session lead by RS.

Draft Science priorities

The draft science priorities identified are separated into high and lower, and shown in Tables 3 and 4 respectively.

Table 3: Draft science priorities (high)

Priority	Justification
Biogeochemical coupling including deep multiphase transport processes - hydro-biogeochemical reactions in GDF conditions - gas production, consumption, reactions and transport especially methane and hydrogen - Coupled THMC processes - fluid movement and radionuclide transport including long timescales - microbial ecology and radiation microbiology of the GDF	Highlight areas of scientific uncertainty where significant progress could be made due to new investigative techniques and tools Focus on radionuclides of particular concern in the UK context
Technological innovation for rock mass characterisation at a range of spatial scales - including technology transfer from other industrial/research sectors - emphasising the 1-100m scale - far-field near-field interface, including fractures and faults	This is timely for the programme. Site investigation will occur in ca. 2015 to 2018. Research is needed to deploy scientific advances and modern technologies that have been developed for other applications.
Learning from natural radioactive analogues and made-made contaminated environments (natural laboratories) **- including natural analogues for the long-term preservation of potential repository materials, such as bentonite clay, copper, *etc* (i.e. as a complement to the suggested natural radioactive analogues**	Provides fundamental underpinning of understanding, model testing and parameterisation in real environmental systems. Applicable to remediation, waste disposal and nuclear power generation impact assessments. Natural Laboratories include both marine and terrestrial environments *e.g.* as a result of accidents such as Fukushima and Chernobyl, natural contamination *e.g.* Uranium mineralisation or contamination as a result of normal operation *e.g*. Irish Sea *etc*.
Innovative approaches to ecosystem/food chain radionuclide uptake and transport processes for key radionuclides relevant to waste disposal facilities and contaminated land	Reducing uncertainty in transfer parameter values on the basis of key radionuclides and environmental variables (such as soil/sediment type) and incorporating spatial and temporal variability. Assessment models are highly sensitive to reported Kd and CR values which exhibit great environmental variability of which we don't yet have a fundamental understanding.
Effects of chronic exposure on plants and animals	Improved understanding of the level of dose causing significant negative impacts on plants and animals. Derivation of suitable benchmark/reference levels. Assessments need to be made for new-build and waste disposal permitting required under legislation which has evolved over the last decade: the current scientific basis needs to be strengthened for chronic exposure (with gaps in knowledge and fundamental data).
Cross-cutting theme: model testing, scientific robustness, uncertainty	Proposals which recognise the cross-cutting theme of model testing, robustness and reduction/quantification of uncertainty will be viewed positively

Table 4: Draft science priorities (lower)

Priority	Justification
Climate change	Where relevant, there is a need to capture the boundary conditions in the high priorities
Background radiation	Doses to the public vary widely across the world. The way that the public are exposed and the potential detriment need further study + explaining in terms of comparative risk
Wildlife dosimetry (see Appendix 1)	Exposure of wildlife has been the subject of recent ICRP publications and more work could be undertaken e.g. sensitivity of organisms during their life – cycle.

Development of recommendations to NERC

CC directed a group discussion asking the EG for recommendations on how the RATE programme should be organised and what should be included in its content. CC used part of the specification, listed below as an aide memoir and to direct the EG in their decisions:

1. Recommendations about the priority research areas, building on previous scoping work and considering radioactivity in the marine environment.
   The science priorities, presented in Table 3 address this. It was noted that while marine needed to be discussed it does not require a centre of excellence specific to this – i.e. it does not require extra emphasis over any other topic.
2. Recommendations about the areas where capacity will be needed to address the priority research areas.
   The EG was asked whether they wanted the money distributed to fund two large consortia or a greater number of smaller consortia. The overwhelming consensus was for two larger consortia. Several cross-cutting requirements/approaches were identified (e.g. modelling, innovation, environmental change).
   The capacity needs were not fully discussed during the meeting. The post-it notes from the exercise to identify capacity needs were later rationalised by the secretariat, and presented in Appendix 3.
3. Recommendations about types of activity to include in the research programme to attract researchers with the required and novel expertise.
   RATE needs to present exciting science, bringing external partners in by advertising in the right places. It should emphasise that it is exciting that Britain is starting a new era, developing future leaders; who will be working together in the future. It is expected that the group/network will be longer lasting than the RATE project itself.
4. Recommendations about elements to include in the research programme to deliver the priority areas (*e.g.* for research, coordination, management, training and impact).
   It was suggested:
   - *That students should be embedded into consortia; they could be based at associated institutions;*
   - *That RATE should proceed with two big consortia: 4 years with associated students;*
   - *That there should be an annual meeting for the whole of RATE and other interested parties;*
   - *That the co-ordination of RATE should have strong links with COGER (and similar groups) to facilitate good external communication and outreach;*

- *That there are no special requirements for data management other than NERC requirements, and;*
- *That students should have summer schools/training events.*

Agreed recommendations

Besides the organisation of the science priorities (presented above) a number of key points were highlighted:

- It was emphasised that the EG were there to provide recommendations, which NERC was not duty bound to follow;
- For the launch NERC could try to get an appropriate minister to mention the RATE programme in a speech at a relevant event in September;
- There is a need for strong public engagement but RATE will not fund specific communication projects/tasks;
- There is a requirement for innovative approaches to ecosystem/ food chain uptake processes etc. the traditional “plant pot type” experimental study should not be welcomed;
- RATE must preserve the research base that there currently is, while the networks and communication pathways should outlast the duration of the RATE programme;
- The UK’s capability should be stronger after the RATE programme than before, and;
- Natural systems should be utilised as natural laboratories.

Close of meeting

RS thanked everyone for attending and bringing their expertise and contributions. He stated that the secretariat would complete the re-organisation of the capacity needs, which would be sent on to the EG for approval. A report of the meeting would be delivered by the end of May for comment by the EG, before submission to NERC.

Appendix 1: Transcript of science ideas 'post-it' notes after the rationalisation process

A transcript of the 'post-it' notes is presented below under the headings and groupings produced as a result of the rationalisation process. The 'post-it' notes text presents the original comments as written by EG members.

Where cluster summaries are provided these were created during the rationalisation process as a method of summarising the 'post-it' notes within that cluster. (H), (M), or (L), indicate that the author of the 'post-it' note considered the science idea to be of high, medium or low priority, respectively.

Group 1: Geosphere (GDF)

Cluster 1: Coupled processes (GDF/Deep borehole)

Cluster summary:

- Cross disciplinary approach.
- Hydro-bio-geochemical reactions at GDF pressure, temperatures, salinity.
- Radio nuclide transport (U/Tc *etc* but also oddities *e.g.* Cl^{36}/ I^{129}).
- Gas production, utilisation, transport (CH_4, H_2).
- Microbial ecology of GDF (extent and colonization of EDZ including weathering).
- Radiation microbiology (including posy-genomics).
- Far field – near field interface (including fractures and faults).
- Coupled biogeochemical modelling (including forward modelling).

Original post-it notes under this cluster:

- Methods for characterising geosphere- learning from oil/ gas industry (H).
- Geological and geophysical GDF site characterisation (H).
- Accurate estimates of background seismicity and active faults (H).
- Assessing optimum depth of burial for radioactive waste (H).
- 3D seismic reflection imaging to extrapolate between boreholes (H).
- Development of novel geophysical monitoring and site characterisation methods for imaging of 3D transport methods at intermediate scales (H).
- Development of site characterisation at the intermediate scale i.e. near field (1-100m) – micro-seismicity and ERT (H).

Cluster 2: Long timescale geosphere evolution and 100 year time scale evolution

Cluster summary:

- Coupled processes.
- Thermal Hydro Mechanical Chemical biological evolution of the geosphere over million year timescales.
- Natural analogues and predictive models, permeability evolution.
- Geosphere sealing over long time scales (wells tunnels *etc*).
- Re-saturation hydro-mechanical evolution due to repository closure and evolution.

Original ‘post-it’ notes under this cluster:

- Production and migration of gasses in a repository environment (M).
- Impact of changes in climate/ geology over long term, *e.g.* glaciations and porosity (M/L).
- Uplift erosion and subsidence (L).
- Tectonics (L).
- Landscape evolution impact on GD (M impact L urgency).
- Additional safety arguments (long groundwater retention times, *e.g.* of retardation, geochemical stability examples (H impact/ M urgency).
- Mechanical chemical thermal hydraulic microbial evolution over million year time scales (analogues, predictability, concepts, models).
- Subsurface geological structures (needs for 1 million year timescale, how can detailed analysis of now inform?) (M).
- (OBS) research into optimisation of planned life, integrity of geological disposal facilities (is 1 million years appropriate in relation to other anthropogenic effects to ecosystems over this timescale?)
- Natural analogues for GD (M impact L urgency).
- Well sealing (sealing technologies and post closure monitoring) (M).

Cluster 3: Site characterisation on both macro and meso scale

Cluster summary:

- Exploit techniques developed in other fields of research.
- Accurate estimate of background seismicity and active faults.
- The role of large scale structures on repository viability.
- State of the art geophysical methods for characterising structure/ fractures. ...
- Imaging meter to 10-meter scale structure, fractures, pathways, using novel geophysical techniques.
- Assessing optimum depth of burial for radioactive waste.
- New novel methods (GPR, EM, conductivity).
- Characterisation of site both before and post completion (shorter timescale).

Original ‘post-it’ notes under this cluster:

- Electromagnetic methods for monitoring sub surface conductivity (M).
- Characterising mechanical and hydraulic structural uncertainty (the role of large scale structural features such as faults which can make or break a repository (H).

Group 2: (no title)

These post-it notes are organised into four clusters as defined by group 2.

Cluster 1: radionuclide behaviour in ecosystems

- Review detection of “hot particles” and dose methodology to individual plants and animals (L).
- Through lab and field studies (*e.g.* near Sellafield) assess speciation, redox, Kd, organic complexes and the role of micro-organisms (M).
- Transfer of radionuclides into plants and animals for biota assessments (L).
- Influence of particle size on interception and retention onto terrestrial foods (M)
- Radionuclide transfer in marine aerosol.
- Gastrointestinal absorption efficiencies for radionuclides by terrestrial fauna
- Influence of soil properties on plant uptake of radionuclides.
- Long-term (>150 years) fate of radionuclides in brown field sites after release from institutional control (*e.g.* LLWR) (M).
- Rhizosphere processes (mycorrhizal associations, enhanced uptake, translocation and tissue distribution).
- (OBS) transfer of radionuclides into plants and animals/ bio accumulation – these are important in the context of potential effects to human populations, rather than protection of individual species *etc*. Could studies of animals inform studies of human risk at low dose? (M/H).

Cluster 2: physical and biogeochemical processes in the deep sub surface

- Impact of mechanical processes on geosphere (M impact, L priority).
- Coupled thermodynamics/ kinetically controlled processes (experiment and modelling).
- Hydrogeological processes influencing radionuclide transport (H impact. M urgency).
- Movement of plutonium in groundwater.
- Behaviour of elements where data is scarce, but potentially important regarding exposure *e.g.* Cl (H).
- Radionuclide chemical processes in geosphere (M impact M urgency).
- (OBS) biogeochemical pathways of radionuclides in the sub surface. Prioritisation is dependent on the relevant information from overseas studies (M/H).
- Thermal processes (H impact M urgency).
- Radionuclide uptake in the geosphere (H impact L urgency).
- Coupled processes impact on GD (H impact H priority).
- I^{129}, Cl^{36} and other oddities (M).
- Speciation and redox behaviour of radioactivity in an evolving disposal environment (H).
- Radionuclide transport processes, organic colloids *etc* (H).
- Convection modelling in fluid saturated rocks (M).
- Which parameter values matter? If data gap how to fill allowing for variability. Models/ safety case (H).
- Review of the current use of radionuclides as tracers, *e.g* in groundwater and oceanic processes. Compile list of outcomes and recommend best practice. (M).

- Hierarchy of models to underpin PA. The geological disposal analogue of dynamic process models.
- Sensitivity analysis of models – what parameters matter and what don't.
- GDF scenarios – pressure, heat salinity and effects of transport.
- Hydraulic evolution of the geosphere (fundamentals conceptual models, prediction, monitoring, numerical models *etc*) (H).
- Linked geochemical fluid flow and geochemical modelling (H).
- Geochemical reactions with rocks and fluid.
- Microbial transformations of radioactive waste. Biotic *vs* abiotic. Gas metabolism. Impact on radioactivity transport especially in a repository (M).
- Geosphere characterisation. Mineralogy geochemistry hydrology microbiology. Colonisation and attenuation of the engineered and disturbed zone by introduced/ extinct microbes (H).
- Radionuclide transfer in the near surface biosphere (plant-microbe interaction including rhizosphere, food chain including BBSRC. Food security?) (H).
- Biogeochemical pathways of radionuclides in the deep sub surface with respect to GDF (coupled processes. Extreme microbiology. Impacts on key long lived radionuclides. Near field to far field transport) (H).
- Radiation biology (impact of radiation, utilise latest genomic/ post genomic tools, build on NERC investment to genomics (environmental genomics and PGP programmes) wide range of model organisms, link to BBSRC systems, chronic *vs* acute impacts) (M).
- The far-field biosphere interface.
- Hydrogen-fact or fiction (H).
- Numerical modelling of flow and transport through the geosphere, any modelling of single discipline (L).
- Sub-surface microbial ecology (what's there, what does it do, how does the community change?)
- Geomicrobial evolution in the repository during operation and post closure. Its effect on transport, mineralisation, weathering *etc* (H).
- Impact of temperature, ionic strength, microorganisms an colloids on radionuclide behaviour (H).
- Radionuclide transport in the geosphere (H impact L urgency).
- Radionuclide immobilisation in the geosphere (H impact L urgency).
- Chemical speciation at realistic concentrations (H).
- Influence of plutonium oxidation state on environmental partitioning.
- Radionuclide retardation on the geosphere (H impact L urgency).
- Groundwater movement (H impact m urgency).
- C^{14} pathways and migration mechanisms in rock/ water and biosphere (H).
- Gas migration through geosphere (H impact L urgency).

Cluster 3: Use of natural analogues and contaminated land to process understanding

- Natural system evidence essential if one million year timescale – ties also to natural background radiation assessment (H).
- (OBS) use of radionuclide tracers in environmental studies. Scope for use of natural tracers (U and Th decay, chain radionuclides – radon *etc*) in environmental studies to support disposal facilities. Also in marine, climate change, nuclear response environment (M/H).
- Marine and aquatic. Our disposal site could be coastal. Our NP sites, many are coastal. Environmental change, sea level rise (M).
- Natural analogues (*e.g.* U mineralisation) have been widely studied in the past, but still have potential for future work. Speciation and migration models and nuclides other than U and Th (M).
- Natural analogues.

Cluster 4: generic/ cross cutting

- Chemical speciation includes model methods of characterising speciation, improved understanding of organic complexation, improved understanding of colloids (H).
- Colloids and complexants – effects on transport and bioavailability.
- Under laboratory conditions, undertake experiments to assess radionuclide transfer in a range of indicator environmental materials.
- Groundwater catchment modelling (impact H, urgency M).
- Rock soil water pathways, and exposure models for long-lived radionuclides (Cl^{36}, C^{14}, Tc^{99}, Cs^{135}, Se^{79} *etc* with an emphasis on C^{14}) (H).
- Long-term movement of radionuclides in groundwater, deep geological and surface waste facilities and impact of climate change (L).
- Testing predictive models for aqueous/ solid sorption (H).
- C^{14} global circulation – impact of increasing levels of C in the environment and how this effects the carbon cycle (H).
- Development of Kd models for radionuclides which are mechanistic, taking account of influence of, for example, pH and organic matter, generically applicable (H).
- Improved understanding of radionuclides that have so far been under-investigated, specifically I^{129}, C^{14}. Definition of contemporary and past sources and environmental transfer pathways, biological uptake.

Group 3: (no title)

Cluster 1: contaminated environments

Cluster summary:

- Contaminated environments. Particles (dosimetry and models).
- Assessment of risks (including post event).
- Decision making re: remediation/ clean-up (marine terrestrial and atmosphere).

'Post-it' notes:

- Radioactive particles in the environment, skin alpha dosimetry, modelling assumptions with respect to particles in models. Characterisation of Sellafield mud patch (M).
- "hot particle" dosimetry for non-human biota (L).
- "hot particle" dosimetry for humans (H).
- Characterisation of the environmental behaviour of "hot particles" – stability, transfer processes, dose (M/L).
- Understanding mechanisms during exposure of contaminated sediments in the next 100,000 years, by falling sea levels – past releases to marine sediments for potential future sea bed releases from GDF (M).
- Data support, assessment of risks from contaminated land. Inadvertent ingestion, transfer to skin, skin to mouth (M/L).
- Baselining part releases from legacy facilities/ sites that will be further developed for new build. Distribution/ accumulation of radionuclides (M).
- Decision making tools for emergency response contaminated land/ soil/water management/ clean-up. Build on Fukushima experience (H).
- Sellafield mud patch – check off shore inventory for trans-uranics and other radionuclides. Model transfer of radionuclides from sediments to biota (M).
- Improve understanding of environmental contamination and its effects post-accident to inform clean-up decision making (marine and terrestrial). Fukushima/ Sellafield (H).
- Irish sea now presents a near equilibrium system. There is still scope to use past Sellafield discharges to characterise speciation *etc* (M/H).
- Marine is low priority (possibly except Irish sea basin?)
- Review lessons learnt from nuclear accidents at Sellafield, Chernobyl, and Fukushima (H).
- Marine studies in Sellafield/ Dounreay area (L).

Cluster 2: Risk analysis and modelling

Cluster summary: Testing models and model structure

- Uncertainty and confidence.
- Inter-connections/ linkages for current situations and future.

'Post-it' notes:

- Review EU legislation and need for UK to develop evidence base (M).
- Review current radiological food chain and indicator material in UK programmes, and make recommendations for additional wild food and wildlife monitoring to include surrogate and transfer factors for different species (H).
- Model verification and validation: CREAM, CROM, ERICA and integration. IAEA SRS 19 update integration (M).
- Impact of environmental variables on dose assessment for wildlife (and humans). Chemical form, soil types, climate and life stage (M).
- Review the use of portable monitoring equipment to detect and quantify the signature of diffuse radionuclide emissions to include alpha, beta and gamma activity. Make recommendations about each use/ test practice (M).
- Across all environmental models where is it important to have site-specific data/ information stochastic approach (M/H).
- Transfer model weaknesses (terrestrial) impact on uncertainties in human exposure estimates (H).
- Testing of human dose assessment models, regulatory/ emergency releases/ biosphere leading to improved monitoring/ measurement capability (H).
- Review of human and non-human radiological assessment tool and models for regulatory purposes. *e.g*. EA, IRAT, PC-CREAM, ERICA *etc*. (H).
- Review strength and weakness of ICRP103 and 108, RAP and ERICA (H)
- Transfer of radio nuclides (not simply transfer factors) stochastic (links to effects but not as far as human) individual to community to population effects. Dosimetry (H).
- Compare current and asses future requirements for radiological assessments in the environment (M)
- Building confidence in safety. Mathematical models, uncertainty. Public understanding. Improving reliability. Learning from climate science community (ESRC link) (H)
- Accurate risk analysis framework, identifying what information is required to reduce uncertainty (H).
- (OBS) detection and characterisation of radionuclides. There is scope for development of radiochemical analysis/ detection techniques, particularly in the marine environment. Drivers – Fukushima, climate change, hydrology related tracer studies (M/H).

Cluster 3: communication (underpins everything)

'Post-it' notes:

- Science communication (H)

- Effective engagement with public media and regulators (H)
- Communication of assessment outputs – more meaningful representation of uncertainty and probability for regulatory decision making/ public engagement. Long term/ short to medium term (H)
- Transfer of knowledge to public, acceptability of disposal (H)

Cluster 4: climate change

'Post-it' notes:

- Evaluation on environmental change on geological disposal (? Up to 1million years) even climate science goes a few hundred years ahead. How to build confidence (ESRC link) (H).
- Impact of future climate change on GD (L).
- Impact of climate change/ sea level rise and flooding on radiological assessments (effluent discharges and scheduled waste) (H).
- Potential impact of climate change on environment transfer and redistribution. Impact on doses from discharges from nuclear sites. Waste disposal facilities (M/L).
- Potential influences of climate change *e.g.* changing redox conditions changing salinity (M/L).

Cluster 5: Background interlinked with animals and plants

Summaries:

- Background baseline assessments, normal and anthropogenic contextual.
- Effect on biota/ biota chemistry.

Background 'Post-it' notes:

- Natural background accurate assessment, wildlife ICRP IAEA (M).
- Background levels of radiation is important but does it need basic research or is it doable with current technology (M).
- Baseline and levels of radioactivity in environment where gaps to give public information and context of incidents (H).
- Accurate assessment of natural background radiation (L).
- Fate of NORM in the environment. Different scenarios and better understanding of exposures (H).
- Review of "baseline" radioactive contamination for regulatory assessment and improved visualisation.

Animals and plants 'post-it' notes:

- (OBS) dosimetry and biological effects in non-human biota. Whilst it is accepted that knowledge of radiation effects in an environmental context is not "mature" we are presumably looking at low dose effects, which are likely to be of low significance, compared with other effects of human activity (agriculture, industry, habitat, destruction *etc*) (M/L).
- Dosimetry prediction in wildlife. Model outcomes don't vary much (L).

- Dosimetry for non-human biota (L).
- Effects on non-human biota. Laboratory studies (M).
- Filling data gaps in RAP framework in order to improve underpinning of DCRLs. Are the DCRL bonds correct (H).
- Biota external exposure in radioactive clouds (M).
- Acute low dose effects studies (L).
- Effects on non-human biota. Field studies in contaminated environments (H).
- Field based studies on doses and effects to organisms to test Moller & Moerssean theories. Chernobyl/ Fukushima (H).
- Improve understanding of radiation effect on biota at different levels (H).
- Doses to non-animal organisms. What do they mean?

Cross cutting (background and plants and animals) ‘post-it’ notes:

- Impacts of NORM discharges on marine wildlife (L).
- Exposure pathways linking to epidemiological study in areas of elevated natural background to input into low dose debate (H).

Appendix 2: Summary of rationalisation stage feedback

After the EG was split into 3 groups to rationalise the science ideas, each group presented oral feedback describing their reorganisation of the post-it' notes (the rationalisation process). The transcript below records this feedback. This was immediately printed off to aid the EG in their discussions which lead to the prioritisation of the science ideas.

Each area for discussion and development into a science priority has been numbered. The format is different for each group, as these notes are transcribed from the oral feedback as it was given.

Group 1 (JL, BL, MK**)**

Split the 'post-it' notes into 3 areas, each member of the group reported 1 area:

1) Coupled processes: 20 post its. Condensed into a few bullet points:

Cross disciplinary.

Hydro-geochemical reactions.

Radionuclide transport – the usual plus oddities (Cl, I).

Colloid transport.

Microbial ecology GDF.

Radiation biology.

Far field/ near field interface – fractures and faults.

Modelling component.

2) Long timescale evolution of couple processes

Natural analogues, predictive models.

Re-seeding geosphere – wells tunnels shafts resealed – predictive way of ensuring it will be sealed.

Shorter timescale – man made evolution of the geosphere.

3) Site characterisation – macro and mesoscale

Background seismicity, what's active.

Imaging, understanding large scale structure.

Bringing in methods from other fields to study fluid flow fractures *etc.*

Optimum depth for burial – rock type at various depths.

Site characterisation before completion, but also post completion.

Group 2 (**GM,** FL, BH, JM**)** reported by GM

Split ‘post-it’ notes into 4 areas, related to key radionuclides:

- Radionuclide behaviour in ecosystems – plant uptake.
- Physical and chemical processes in deep sub surface.
- Use of natural analogues and contaminated land to process understanding – included marine, Irish sea.
- Generic/ cross cutting – Kd speciation.

Group 3 (JS, NC, PL, JB, AM, MS**)** reported by JS

Split ‘post-it’ notes into 6 areas.

- Research into communication is important outside of this, but to actually communicate is important – ensure the legacy of this programme (communicate at RATE programme level rather than within individual projects).
- Climate change – doses from sites, geological disposal, redox conditions.
- Background – quantification of natural background, monitoring – is it sufficient to give us a baseline?
- Animals and plants – effects, dosimetry on plants and animals.
- Contaminated environments – existing contaminated lands, contaminated environments from Fukushima, Chernobyl, hot particles, characterisation, emergency response, lessons learnt, improving post-accident clean up. Characterisation – response – clean-up of contaminated land.
- Risk analysis and modelling – members of the public don’t believe the available models, therefore a good starting point is to evaluate models.
    - Broad group. Testing of models and model structures.
    - Uncertainty and confidence. There is a need to think about future situations, how would these impact existing models.
    - Testing models. Processes and structures of available models.
    - Importance of linking what we do to the model that is needed – infinite model of environment processes – there is a need to study those that will improve model predictions.

Appendix 3: Transcript of capacity needs ‘post-it’ notes after organisation by the secretariat

Transcript of capacity needs ‘post-it’ notes after organisation by the secretariat

Group 1: People

How to achieve RATE objectives

- Involve PhDs in consortia.
- Need to train early career researchers. PDRAs who go onto be lecturers or researchers in industry (H).
- Long-term career path to “subject matter expert”.
- Not only PhDs and postdocs, also researchers who can have an impact within 3 years to end users.
- Radiochemists (analysis at environmental levels, method development).
- Need to support industry for site surveying and selection (M).
- Training (distributed courses, APTS/SMSTC programmes) NERC environmental statistics course.
- Field and laboratory radioecology skills.
- Fellowships.
- DTC.
- PhD student case.
- Doctoral training network (NERC DTPs will kill studentships in environmental radioactivity, focused resources will reduce overall capacity, DTN allows wide coverage-integration).
- Well-trained people for the monitoring industry in broad sense (M).
- Lack of experimental scientists in environmental radiochemistry- accident response. Dominance of modelling and consultants who don’t do data production.
- Build capacity through attracting new researchers at PI and postdoc level into the field. Fund a strictly limited number of studentships associated with the programme.
- Need promotional communication – need to show how “sexy” contributing to the safe development of a green energy future is to help recruitment. Need to link to offer capacity/ skills development programmes.
- Communication of risks *e.g.* 1:1 million.
- Competent staff familiar with sampling and analysis of environmental material.
- Retention of current expertise – radiochemists low level.
- Cohort of PhD students – PDRAs/ fellowships.
- Address sustainability of funding or they will go elsewhere.
- Knowledge transfer - old(ish) to young. Novel ways?
- Underground research – capability in all fields of research. Facility and people capacity (H).
- Geosciences (including geochemistry, geology, geophysics, geomicrobiology). Strong competition with other industries and under capacity.

Multi-disciplinarily approaches

- Approaches which integrate young scientists with community. *e.g.* STAR and other networks, IAEA programmes *e.g.* EMRAS. Mentoring, motivation, EU platforms.
- PhD students with multidisciplinary skills (H).
- Researchers with multidisciplinary capability between mechanics /hydraulics /chemistry/ microbiology /geology/ geophysics.
- Environmental scientists with experimental knowledge/ breadth.
- Support for a NERC DTC in the broad RATE area (H).
- Experiment and modelling, multi-disciplinary, real work.
- Research, environmental modelling/ statistics skills.
- Radiation measurement/ detectors/ dosimetry skills.
- Cross industry training, skills people from other fields.
- Radioactivity in the environment – work coordination/ alignment with EPSRC champion.
- Expertise areas – aquatic ecosystem, marine sediment processes, soil scientists, ruminant experts need to integrate.
- Alignment of GDF skills with carbon capture, gas storage, oil programmes to meet UK needs.
- Training to PhD and PDRA status including areas such as radiochemistry, modelling (especially coupled processes). Subsurface characterisation, radiation science, and radiation biology (omics). Cross disciplinary bio/ geo.
- Build capacity in marine and estuarine processes.

Group 2: Money

Infrastructure

- NSAN: national skills academy (nuclear). Industry sponsorship to show support of *e.g.* Postgraduates.
- NERC facility.
- Potential cost liability etc. of using overseas facilities.

Networks

- Restrict this call to x postdocs, y studentships, no facilities/ infrastructure.
- Networked academic community to cover wide range of relevant subject areas-COGER.
- COGER.
- After RATE work opportunities for trainees in industry – industry sponsorship
- Need = more funds. How = nuclear industry (particularly new operators) should be contributing to common funding pot, similar to FDP.
- Infrastructure – better cross council links (+EU). EPRSC/NERC good, strong links to others? Workshop? Stakeholder engagement. Rate = gearing network.

Group 3: facilities

Networks

- Student/ postdoctoral placements for part of their studies into NDA/EA. “experience the longer term nature of the rad waste programme”.
- Radiochemistry; geochemists/ geologists; modellers; scientists with KT and public engagement ability.
- Mechanisms for mentoring postgraduates with “applied” organisations/advisory/regulatory.
- Steering group communication. Annual conference (technical) + website+ list of publications + knowledge exchange, *e.g.* through science week, BBC, public engagement.
- Use some funds to establish a long-lasting network – or does COGER do this already?
- Gearing UK programme with engagement with EU.
- Data archive of environmental data with links to methodology. Ability to link data from different sites.

Facilities – URLs

- Underground research – capability in all fields of research. Facility and people capacity (H).
- Student/ postdoc work in research facilities *e.g.* URLs and projects.
- Use of overseas underground research labs – *e.g.* Aspo.

Facilities – ‘active’

- Facilities, access to hot labs, underground research facility, international links facilities/ programmes, Sweden/ Korea/Switzerland.
- ‘Active’ researchers and ‘active’ facilities.
- Mechanisms to share radioactive labs with organisations outside academic network.
- Access to facilities for ‘active’ work, *e.g.* NNL.
- “Active” facilities, why NNL?

Facilities – not ‘active’, not URL

- Need state of the art labs. How = review NNL BTL use and access model, centre for environmental radioactivity.
- Use national physical laboratory (NPL), supplying environmental samples as standard, where analytical facilities test their competence for specific radionuclide, *e.g.* sediments/ biota.
- Build capacity in marine and estuarine processes.
- (OBS) laboratory equipment properly calibrated for experiments with animals and plants, *e.g.* radiation facility as used at Cefas, Lowestoft.
- Experimental facilities for uptake/effects studies.
- Facilities/ infrastructure. Samples! Site for GDF or analogue.

Annex 2

Summary of comments received via the web based opportunity to comment and CoRWM, suggested secretariat revisions and EG responses

Science priorities	**Secretariat comments**	**Suggested action for EG report revision**	**EG Member responses**	**Action taken**
I would comment that a full understanding of the coupled THMC processes remains a challenge after many years of research. In particular, coupling mechanical processes is difficult given the very different time-scales associated with mechanical effects compared to others. In many ways, much of the detailed H-M coupling can be addressed by post construction characterisation rather than requiring detail understanding of short time-scale processes. Of perhaps more interest are other couplings. In particular the Micro-biological and multi-phase flow processes. The coupling of these processes with flow and chemistry in the near-field and at the near/far field boundary is a potentially important issue for the demonstration of the PCSC.	Agreed	None	Agreed - a range of couplings needs to be considered, and that RWMD thinking, knowledge and experience on THMCG coupled processes is more advanced than couplings involving 'B'. That said, the significance of 'B' couplings is something for consideration in prioritising further work in this field; it is not instantly obvious what is being suggested here and how it can proceed in a staged manner as the MRWS process proceeds (can work be meaningfully undertaken in the	None

			absence of access underground?)	
Yes but with some conditionality as specified below [refers to 4th comment of Missing Science Priorities]				
I believe the balance of the priorities is skewed away from the biosphere and ecosystem. It is, after all, the living component of our environment that is most at risk and represents the greatest complexity and is the most vulnerable. I believe this was due to the balance of expertise in the Rate Group being overly in the physical environment rather than the living one. As a lichenologist I am aware the lichens (and to some extent bryophytes) have extraordinary and unique ability to accumulate, and greatly concentrate, radionuclides as they are heavy metals in the main. Invertebrates (and some vertebrates) consume lichens feeding the radioactivity into the natural food chain and into food webs. Although there is, perhaps justifiably, vested interest in prioritizing agriculture, there should be more emphasis on considering the natural ecosystem justified by it being under such unprecedented and serious threat.	Agreed but this is part of the biosphere so is implicitly included in the scope of the call.	None	Non-human biota (flora and fauna) are already considered in safety case studies undertaken to date for a GDF. We have trouble seeing that a GDF, appropriately implemented to meet regulations, poses an "unprecedented and serious threat" to the biosphere. This does seem rather emotive language. Agree that this will be covered although not spelt out in the detail of the comment I am not sure what the concept of 'risk' might represent to non-living components of our environment? What has changed since the studies of	None

			weapons fallout in lichens and foodchains they support?	
I am aware of the drive for some work on the big projects (geological disposal etc) but much of this work will be funded if needed as these types of projects progress. I would therefore suggest that the funding should be more focussed on work areas which need to be addressed in the near term, to ensure proportionate actions and thus allow reductions in costs. 'Smaller' individual issues (but generic issues which are much greater in number) such as RCL [radioactively contaminated land] or new landfill sites need to have research focussed on them. For example, large amounts of LLW waste could go to suitable landfill sites if the necessary work were undertaken to provide generic assessments and thus bring about significant savings both to the nuclear and non-nuclear sectors in the near term. Equally suitable research could allow re-development of current contaminated sites.	Agreed that the projects funded under RATE need to be generic and not site-specific or close to operational needs.	None	This is a personal opinion; no comment. However, for RWMD to justify funding the NERC programme the successful proposals must have relevance to geological disposal. I agree with this comment-NERC is not intended to address an industry need, so should not be too close to operational needs.	None
The identified priorities are all well-chosen but lack an important dimension. Physical processing dimension is the impacts of changes in local environments (in and around the GDF) with the man- made barriers. To establish the link, and include the results in modelling, impacts have to be quantified in terms of physico-chemical parameters, e.g., concentration, activities, pressure, temperature. The way in which the topics are addressed seems too phenomenological and not well designed to yield data to couple to performance – based models.	This relates to where the boundary (albeit artificial) is between the NERC and EPSRC remits (about the edge of the engineered part of a GDF).	None	No additional comment. Also, I am not sure it is for RATE to develop performance assessment models Agree with not engineering	None
Missing Science Priorities				
I would have liked to have seen more emphasis on	RATE funding is	None	The comment has	None

remediation and decommissioning - specifically effective and emerging technologies for improved RA effluent, water and contaminated land remediation and management (including for currently problematic radionuclides), for both legacy wastes and for emergency situations such as nuclear accidents or deliberate release (e.g. "dirty bomb" scenarios). This is an important area requiring expertise development within the UK, and where fundamental research is still required, and which could usefully inform several of the other priority areas listed. I note that these areas were at least partly discussed under the Group 3 discussions but were not carried through to the final priority recommendations.	limited		minimal interaction with the remit of NDA RWMD, nothing further to add. Much of this is out of scope for RATE and NERC. Effluent treatment, for example, has been addressed extensively in the EPSRC Diamond consortium, while dirty bomb response is part of the cross Council Global Uncertainties programme. I have some sympathy for this comment- not least that NORM for instance remains an issue also that needs research. Agree with the comment but also with the response in that RATE needs to prioritise.	
1). see comment to Q6 above [first of the Science Priorities comments above] on coupled processes. 2). I also believe that there is a need to further develop our understanding of very low permeability flow and transport. Whilst advances in other fields	Agreed	None	RWMD is already progressing work that responds to the many issues noted in this comment.	None

can usefully be assimilated within multi-disciplinary work within RATE, the radioactive waste community (and CCS) has a particular interest in very low permeability flow and transport processes. The characterisation of such low permeability environments in terms of water and gas migration is currently being addressed in a number of URL facilities internationally. When the UK begins construction of a GDF there will be a need to characterise the accessible near field geological environment and show that the scientific community can understand the detail of any measurements and characterisation experiments. These are often challenging datasets to interpret in detail, and I would urge the RATE programme to prioritise engagement in international URL programmes and modelling task force projects. 3). I would also recommend a higher priority to the development of surface and borehole characterisation methods. The initial phases of a UK GDF programme will focus on this issue and it previously proved challenging to design and interpret such a programme. Whilst techniques and understanding have advanced internationally, it is not clear whether the international work represents the best approach for a potentially more complex UK geological setting. For example, most popular flow logging tools were developed 10-15 years ago and were initially intended for relatively 'clean' granite settings. Many other remote sensing approaches were developed within the Scandinavian and Swiss programmes, again targeted at their particular geological priorities. It would be useful to pursue remote characterisation of deep low permeability environments directly in a UK setting. The current interest in Shale Gas and CSS perhaps provides an opportunity to share technology development. 4).			I don't particularly disagree but site characterisation, and the tools needed to do so (including credible models), are surely the responsibility of the implementers? Boreholes or work in overseas GDFs are potentially very costly, and is this really so important that a very large proportion of the RATE budget should be committed to it? In general models and model development are important issues.	

Modelling capability and tools have moved on since the initial round of nuclear industry specific code development. These initial tools were extensively verified and, so far as could be (!), validated. Whilst some of these tools remain, other tools from outside the industry are increasingly used. These have all been extensively used and whist they have been benchmarked against well understood test cases, many have not undergone the level of verification undertaken for modelling tools of the 1980s. Recent work on multi-phase flow models shows that there remain assumptions embedded within codes that differ between codes and which affect results. Such code comparison exercises have a value beyond simple checking for errors but can often highlight assumptions that would otherwise be overlooked and which may be important in the specific applications required for radioactive waste disposal studies - even when they have been shown to be appropriate simplifications in more conventional applications. Whilst there is not sufficient resource available to support large international code comparison exercises such as were undertaken in the 1980s, I would encourage support for UK involvement in international modelling task forces where there is the opportunity to apply UK modelling to the same problems being addressed by the international modelling community.				
There does not appear to be any recognition of the need to investigate saline environments. Much of the current geochemical modelling data is not able to handle saline systems the same is true for our microbiology understanding. Deep UK ground-waters are saline to some extent consequently there is a real need to ensure saline systems are properly considered. There is a problem here because of the	No environments are explicitly included or excluded in the EG report and may be considered.	None	RWMD recognises the need to consider a range of geological environments, with associated e.g. groundwater chemistry, in its	None

difficulty of accessing these ground-waters for experimentation.			current work programme.	
The main Science Priorities defined are highly relevant but it is disappointing that 'Marine' aspects have been diminished from their original billing. This must in part reflect the fact that no marine champions were involved in the EG. The recent Fukushima incident, for example, showed that France rather than the UK was foremost in demonstrating expertise in hydrodynamic modelling of radionuclide dispersion. For the sake of resilience the UK should have a good grip on such a specialism. With new-build likely to have a strong estuarine expression then updated hydrodynamic models are highly relevant there. Effective operation of such models requires a broad range of empirically-derived marine data (some radiometric). This is one deficiency amongst others that could be cited for marine environmental radioactivity.	The EG decided not to make marine a special case but include it throughout.	None	The OSPAR agreement will severely limit operational discharges of radioactivity to sea from new build power stations. Impact in an accident will surely be part of the site operator's emergency response planning, and thus the operator's responsibility. Perhaps make the inclusion of marine more apparent. Agree that marine dispersion and impact assessment is important, which I think the EG also agreed. What we didn't agree with however was that a new specific centre of excellence/lab should be set up with the limited	The text in the executive summary has been amended.

			funding available.	
Effects on natural ecosystem and how that related to agriculture and human health.	Agreed but this is part of the biosphere so is implicitly included in the scope of the call.	None	Nothing further to add. Agree	None
Thus 'smaller' individual issues (but generic issues which are much greater in number) such as RCL or new landfill sites need to have research focussed on them. For example, large amounts of LLW waste could go to suitable landfill sites if the necessary work were undertaken to provide generic assessments and thus bring about significant savings both to the nuclear and non-nuclear sectors in the near term. Equally suitable research could allow re-development of current contaminated sites.	Agreed that the projects funded under RATE need to be generic and not site-specific or close to operational needs.	None	Comment only, nothing further to add. OK, but are generic radiological assessments of landfill really appropriate for RATE? Are they not more the responsibility of the site operators and/or waste producers? Agree	None
Data on impacts is also going to require validation by focussed experiment,	Agreed	None	Impacts of what on what? This is a vague comment! However the principle of appropriately focussed experimental programmes is endorsed.	None
Delivery				
Yes but it remains to be seen how well the two consortia will reach into and interact with the scientific community. The NERC Expert Group document	Agreed	None	Agreed, and don't rule out international expertise as	None

suggests that RATE should bring in external partners and it is hoped that this will include interacting with other established centres of ER expertise in the UK.			providing a meaningful input to the work.	
Although I agree that a significant proportion of the funding should be allocated to consortia bids, I feel that a proportion should also be allocated to smaller projects to encourage innovative research and build more widespread capability in the field.	This is a NERC/PEB decision.	None	The expert group considered the best way of developing capacity was to invest in 2-3 consortia. There was a strong emphasis that they should cover at least 3 institutions each. I would support this.	None
The EG has indentified 5 priority areas. However they also recommend that only 2 x £4M consortia are funded. Some of the areas are more specifically outlined and may be suitable for smaller grants, whereas other areas more obviously require a larger grouping to meet the challenges outlined. Therefore limiting to 2 funded consortia would effectively reduce the number fundable priority areas. A more flexible approach allowing consortia form between £1M - 4M may well allow more diversity in applications and ultimately support research and capacity development more broadly across the 5 priority areas. If 2 x £4M delivery in retained, then the programme team will have to carefully think how consortia building (via the town meeting?) is managed so that the priority areas are all reflected/ retained in the proposals submitted.	2 consortia is the EG recommendation but this is a NERC/PEB decision.	None	I did not think the intention was for <u>all</u> priority areas to be covered. This would be a useful model so we should try to be flexible.	None
Missed capacity needs				
Many individuals associated with previous GDF programmes in the UK are approaching the end of their careers and as well as developing new capacity,	Agreed	None	Agreed. Agreed	None

the RATE programme should look at how to ensure the experience from these individuals is handed on to the next generation. This is acknowledged by the intent to involve non-academic organisations (where many such individuals are based) but should perhaps be given explicit emphasis. This might be fostered by an expanded expert group to provide more detailed technical support to the programme.				
I think modelling as a specific discipline needs a higher priority. In the current form the EG report appears to relegate modelling to a supporting role, rather than as a priority discipline in its own right.	The EG thought that modelling was a cross cutting activity rather than supporting.	None	Modelling is a tool deployed to progress understanding of an issue; it is not a specific discipline although you do need SQEP staff to understand what a software tool has been designed to do, its limitations, input data requirements, and how the output can be interpreted in the remit of the scientific or engineering discipline (e.g.) that is being scoped. Code development is s specific discipline, but hopefully no code writing will be included in this work (use will be made of existing toolkits).	None

			Cross cutting and bedded in the science.	
There is a widely held belief that expertise in environmental radioactivity and radiometrics is in short supply. One of the best ways of building this capacity is through a broad range of PhDs. The current RATE approach will only partly address this. A specific pot of money should have been allocated to allow academic institutions, unlikely to be invited to participate in the two consortia, to compete.	This is a NERC/PEB decision. The EG recognised that some of the PhDs would be at institutes that were not necessarily main consortia members.	None	This is an opinion. NDA RWMD is supporting a range of PhDs, e.g. through EPSRC funding and EC collaboration. I think that the EG hoped this to be the case also.	None
The UK is overly reliant on natural analogues and modelling. Nature holds valid and important clues but the true significance of these can only be judged by supporting experimental work.	We disagree that the UK is over reliant on analogues and modelling which are an important part of understanding how systems may behave over long time scales. We agree that supporting experimental work is necessary.	None	Overly reliant on natural analogues and modelling in what context? This comment requires further development to enhance meaning. Reliant yes because they are such powerful tools, not overly.	None
Any other comments				
I am pleased to see that the skills shortage in Geoscience has been recognized, but hydrogeology is also a key area of geoscience of importance to Nuclear. Regarding capacity needs, there needs to	Agreed	None	Agreed, but care needs to be used in ensuring PhD and PDRA funding is on	None

be sufficient investment within the projects in PDRAs and early career researchers; these areas should not be neglected at the expense of PhD studentships. This will help to retain existing "capacity" in the form of suitably trained PhD and PDRAs from recent projects (e.g. BIGRAD, DIAMOND, BANDD) and also attracting new researchers to the area - essential in areas where there are recognized skills shortage (e.g. Geosciences). This was recognized by the EG, as reported in Appendix 3: "Build capacity through attracting new researchers at PI and postdoc level into the field"; "Fund a strictly limited number of studentships associated with the programme."			topics of interest to e.g. radwaste management / disposal in the UK context, and not on issues purely of academic interest. Agree.	
There will be three different technical objectives to a new UK GDF programme: site selection and characterisation, demonstration of scientific understanding of all processes relied upon and accounted for in the PCSC, and the development of the PCSC itself. The proposed RATE recommendations addresses these requirements but, I believe, prioritises the science to underpin the PCSC. I would encourage more explicit consideration of the needs for site selection and the initial characterisation of candidate site, and the approaches that will be required to understand measurements from a URL/experimental programme during GDF construction. Indeed, these issues will be the first that the UK needs to solve, and will likely be the priorities at the time that the RATE programme is delivering the new scientific capability to the industry.	This was discussed at the EG meeting and considered to be important but is the responsibility of the operators.	None	The point being made is reasonable, although this does not indicate a gap in NDA RWMD's programme. The RATE programme is complementary to RWMD's needs driven research programme and duplication is not beneficial. Agree with proposed response Not for NERC, why should we choose sites.	None
It is likely that the two consortia will operate in an insular way and meet their needs using their existing network of collaborators. Should this occur, then real expertise or technological innovation existing in other centres may be missed/overlooked. How will NERC	This is a NERC/PEB decision. It is proposed that there will be a	None	Nothing further to add. Stress importance of coordination.	None

or the consortia work to act against such a tendency? I can't help thinking that NERC is providing significant funding for an area where perhaps a much greater financial input should have been expected from the NDA and the Environment Agency.	coordination role to facilitate post award integration. RATE funding is limited!			
Radio-analytical training will underpin many of the proposed scientific priorities. As such, a summer school on radio-analytical techniques should be included within the RATE program. Such a summer school would also have wider benefits to the nuclear and environmental communities.	Up to those submitting bids!	None	A good idea. The bids overall should have both a training element, and an outreach element such that non-participating organisations can keep up with progress / learn from work being undertaken during the lifetime of the consortia arrangement. There is a mechanism.	None
I am very supportive of the document and its recommendations. Once the RATE call is announced, I would urge NERC to ensure that it includes all groups/interested parties in town meetings. I would suggest a proactive approach may be useful here. For example, direct approaches to organisations etc may be necessary to check that they are aware of the call.	Agreed	None	Agreed. Agreed.	None
The RATE funded work should be fully open and available to all. Commercial confidentiality and intellectual property rights should be avoided at all costs; otherwise the value of any work undertaken will be significantly reduced.	Agreed but use of IP needs to be agreed by all consortia members.	None	Needs to be considered at a detailed level as part of setting up consortia	None

			arrangements, but the general principle is agreed.	
The data base on radionuclide properties such as sorption on natural media, aqueous solubility and the formation under natural conditions of solubility - limiting compounds is woefully inadequate. The degree of confidence that can be placed on modelling is, correspondingly, low. Data collection and critical evaluation of data is a deeply dull topic but remains an area of continuing weakness. The impacts, for example of biogeochemical processes, can only be critically assessed if benchmarks are established.	Up to those submitting bids	None	Any database for, in this case, radwaste disposal uses needs to be focussed on key radionuclides of post-closure significance – 'stamp-collecting' data that are of minimal interest to the Environmental Safety Case for a GDF is not beneficial on many fronts. The third sentence of the point, starting "Data collection…" is accurate in so far as collection and evaluation being key aspects of any forward programme. The point needs to be honed, to emphasise that data on key issues from a safety case perspective should be prioritised. This is a deeply dull topic. Yes, it needs to be done, but I	None

			cannot see how NERC would defend spending RATE money on this. It is surely for the users of these databases (implementers, consultants) to do this work.	

Specific Comments from CoRWM on EG Science Priorities

Priority	CoRWM comments	Secretariat comments	Suggested action for EG report revision	EG Member response	Action taken
Biogeochemical coupling including deep multiphase transport processes - hydro-biogeochemical reactions in GDF conditions - gas production, consumption, reactions and transport especially methane and hydrogen - Coupled THMC processes - fluid movement and radionuclide transport including long timescales - microbial ecology and radiation microbiology of the GDF	• Research in this area would support the implementation of geological disposal in the UK and so is to be encouraged. What is not clear is whether it is more important than, e.g. research on the evolution of geological barriers and on groundwater flow patterns and rates over long time periods. • While much of this research fits within RWMD's "needs-driven" and the EA's programmes some is likely to be of the sort appropriate for NERC funding.	It is for the consortia to propose what aspects to cover. The RATE budget is finite. Specific operator needs driven research is not considered to be an explicit part of RATE.		RWMD is already undertaking work on THMC coupling (e.g. DECOVALEX project), and we have a rich history considering GDF-derived gas generation and migration. We have undertaken some work in the field of microbiology and the potential influence this could have in an evolving GDF, and recognise the potential need for some further work here, appropriately focussed to address	

	• We are not sure that all topics should be under the heading “biogeochemical coupling” when the “bio” part may be trivial for the far field outside of the local GDF domain. Coupled THMC processes should perhaps be a priority area in itself not under the “biogeochemical coupling” header. • The wording on gas research confuses bulk and radioactive gases. Hydrogen is by many orders of magnitude the dominant bulk gas. Its production is by metal corrosion, at rates that depend on the amounts of water present in the GDF, hence there is joint NERC and EPSRC interest here. The primary question for methane is the rate of production of radioactive methane from metal corrosion, which is mainly an EPSRC topic and which to some extent has been covered by the previous NDA/EPSRC consortia call of 2010 on	Agreed Disagree – in an ILW context methane and carbon dioxide are the main bulk gasses and both will contain C^{14} in significant amounts. Hydrogen is also the result of radiolysis.	Suggest putting the bio in ( ) as (Bio)geochemical. None	key issues from an ESC perspective. I would seriously suggest any organisation considering developing a proposal against this ‘Priority’ speaks to RWMD at the outset, to ensure the proposal is demonstrably aware of RWMD work to date and overall positioning on matters raised in this ‘Priority’. Yes, although not convinced that the “bio” part may be trivial in the far field. OK, seems sensible There is much concern about methane production via microbiological processes, utilising the cellulose-based materials in ILW. This poses an additional concern to the one highlighted here. This is clearly a NERC topic appropriate for	Put bio in () None

	wasteform/container/near-field issues. • The last bullet should be "a GDF" or "potential GDFs", not "the GDF".	Agreed	Change text throughout to 'a GDF' as appropriate.	RATE (as is the biogeochemical fate of methane in and around the GDF).	Text changed as proposed
Technological innovation for rock mass characterisation at a range of spatial scales - including technology transfer from other industrial/research sectors - emphasising the 1-100m scale - far-field near-field interface, including fractures and faults	• This is a high priority area for geological disposal R&D. • We note that rock mass characterisation at the 1-100m scale is relevant to both the near field (EPSRC) and the far field (NERC). There needs to be NERC funded research in the far field and at the interface with the near field, such as developments in characterisation and monitoring of the long term evolution of the system which involves subsurface geophysics. We trust NERC will take account of potential overlap with EPSRC programmes when assessing proposals. • We also note that there is a need for both fundamental research (of the sort appropriate for	Agreed Agreed Agreed	None None None	This is clearly an area of interest to RWMD. Techniques are already available for rock mass characterisation at a range of spatial scales, and are utilised by e.g. sister organisations. Any proposal needs to be cognisant of this, rather than painting an unnecessarily 'bleak' picture.	None

	NERC funding) and RWMD "needs driven" research in this area. For example, near-field *in situ* characterisation will be dominated by the latter but some research may be fundamental work on reaction mechanisms to occlude porosity. Another example is fault characterisation and behaviour. Some research will be "how do faults work, how do they evolve, and what signatures can be used to assess this", whereas other work will be on imaging and documenting faults at better scales than present, the latter being mainly "needs-driven". We trust NERC will take account of the requirement for both "needs driven" and more fundamental research when assessing proposals. • Technology transfer is, largely, for RWMD to fund (as SLCs do in the case of other radioactive waste management areas). For	Agreed	None		

	NERC the priority should be for improved understanding, and then working with RWMD to ensure that the benefits of innovative ideas are realised in practice.				
Learning from natural radioactive analogues and made-made contaminated environments (natural laboratories)	• This is not such a high priority since much research has been done on natural analogues and on contaminated environments (Irish Sea, Chernobyl) already. Some of it is for organisations other than NERC to fund (e.g. RWMD should fund all the GDF analogue studies).	Disagree – There is still a lot of scope to learn from Fukushima etc. Agree that it is for operator to fund GDF analogues.	None	An Environmental Safety Case considers both qualitative and quantitative understanding. Demonstrating learning from natural analogues, to support a safety case, is a key area and one that should be appropriately prioritised. The choice of natural analogues themselves should be aligned with the safety functions in a safety case, and not merely of tangential academic interest. There is still much to learn from "natural laboratories". To increase confidence in radiological models they must be	None

				tested, where possible, in the field. Natural laboratories, including Chernobyl, Irish Sea and Fukushima present possibilities for such model testing. Equally, radiation effects studies on animals must be conducted in field as well as lab conditions. Disagree, I think this is key (not least because natural lab better than anything we could design)	
Innovative approaches to ecosystem/food chain radionuclide uptake processes for key radionuclides relevant to waste disposal facilities and contaminated land	• Much of the information required for use in current safety assessments for waste disposal facilities and for evaluating options for managing contaminated land is available. If more site specific information is needed, operators should fund its collection.	Disagree. But agree that site specific studies are responsibility of operators.	None	The key word here is innovative and seeks to identify novel approaches which validate the current understanding. It is true that much information for use in current safety assessments is available, but there is still high uncertainty in transfer parameters for some key radionuclides. I think there is some	None

				suggestion that in fact we do not know very well some of the rates and processes and should aim to do better- some of the models being used are more than 30 years old and have not kept up with developments in other fields	
Effects of chronic exposure on plants and animals	• This is not a really a high priority for new build or waste disposal (both mentioned in the text justifying the choice). • It is also important that any UK research on this topic is linked to research programmes in other countries. We should not be duplicating work elsewhere but complementing it and filling in gaps.	Justification requires correcting. Agree that international experience should be considered.	Revise justification None	Non-human biota (flora and fauna) is already considered in safety case studies undertaken to date for a GDF. Wildlife impacts may be highly unlikely from new build and waste disposal, but the lesson from Chernobyl and Fukushima is that there is a media focus on effects on wildlife due to great public interest in this issue. Rightly or wrongly, stories about non-breeding birds at Chernobyl and "mutant" butterflies at	Justification revised None

				Fukushima influence public opinion concerning both New Build and waste disposal (probably more than any number of safety case models, and I say this as a modeller!). Note that some studies at Chernobyl apparently find significant effects on wildlife at very low dose rates. UK science needs to address this issue as part of international work in this area.	
Cross-cutting theme: model testing, scientific robustness, uncertainty	• It is sensible to have this as a cross-cutting theme.	Agreed	None	Agreed – sensible cross cutting theme, which needs to be progressed at the outset of the project (as it could influence works therein), and not as an after-thought.	None
Draft science priorities (lower)					
Climate change	• We agree that climate change as such is not a research priority for RATE. However, it needs to be taken into account in various ways in other	It is up to those submitting bids to include as appropriate.	None	RWMD needs to be aware of the implications of climate change for its programme of work, but <u>leading</u>	None

	research areas and this is not just a matter of consideration of "boundary conditions" as indicated in the EG report.			significant work in this vast scientific area is probably not justified. I agree with the Secretariat comment.	
Background radiation	• The justifying text mentions doses to the public, the associated detriment and comparative risks. In our view, these are not topics to which NERC should be devoting any funding.	Is this MRC area of responsibility?	Do we need to change text or justification?	Not sure what the point being made actually is – further detail to be provided. We certainly need to establish a radioactive 'baseline' at any site under investigation, achieved through an appropriate monitoring programme – is this what is noted? I don't think this is MRC. Risk from environmental pollutants seems to me to be clearly NERC science. MRC would study e.g. human epidemiology, cellular processes leading to cancer. No, I think this is key since it provides a baseline on which we operate- I	None

				reiterate as well that NORM and LLW are being produced in large quantities so time to do something about it. I would agree that the text requires changing. At the EG meeting we noted that research into low doses on humans was covered elsewhere by for example the MELODI programme etc and therefore was not a priority for NERC funding.	
Wildlife dosimetry	• This is low priority and any UK research must be linked to studies in other countries.	Agreed	None	Non-human biota (flora and fauna) is already considered in safety case studies undertaken to date for a GDF. We certainly need to establish a radioactive 'baseline' at any site under investigation, achieved through an appropriate monitoring programme – this will include flora and fauna. The case for	None

				further study in this area needs much greater consideration and justification But part of the bio/eco sphere	