EPSRC
Engineering and Physical Sciences Research Council

UK-India Workshop to Identify Areas of Potential Collaboration in Civil Nuclear

22 - 23 March, Guoman Cumberland Hotel - London

1.0 Background

The UK and India have identified collaboration in civil nuclear research as a priority area. This follows successful joint working on non-nuclear renewable energy.

To scope these opportunities an Indian delegation led by then Chairman, Atomic Energy Commission Dr. Kakodkar, toured UK centres of excellence in March 2009. In return, a UK academic team (supported by the FCO and the RCUK office) was hosted by several Indian institutes, most notably the Bhabha Atomic Research Centre (BARC) in Mumbai and the Indira Gandhi Centre for Atomic Research (IGCAR) in Kalpakkam.

One of the aspects of the visit that most impressed the UK team was the high level of nuclear expertise vested in the Indian researchers and the clear national strategy of development and deployment of nuclear power technologies.

The discussion also made clear that the Indian scientists were particularly keen on developing collaborations that would enable work to be carried out using UK high-end facilities such as ISIS, Diamond and HiPER.

Potential areas of collaboration with benefits to both UK and India include:

- Thermal Hydraulics and Structural mechanics.
- Fuel design, PIE (includes in pile performance) & fabrication.
- Radiation damage processes.
- Materials including:
    - ODS
    - Carbon (including graphite, carbon waste materials, SiC).
    - Materials performance, Corrosion.
    - Non-destructive evaluation.
    - Failure mechanisms including creep.
- Reactor Physics (codes, design).

- Waste forms and management (including glass, ceramic and composite).

Education and Training is a cross cutting possible area of collaboration.

It is clear that there are benefits to closer collaboration and a workshop was proposed as a route to investigate these.

1.1 Aims

The workshop was principally aimed at:

- Building understanding between the two communities on relative strengths, activities and the overall UK/India landscape.
- Sharing knowledge between key UK/Indian researchers.
- Raising wider awareness of UK/Indian capabilities.

The delegation also recommended an exchange of researchers as a further useful way to build relationships. As such the workshop also identified and developed possible researcher exchange opportunities to:

- Continue to develop UK/Indian networks both at the individual exchange researcher level and at the community level.
- Demonstrate the value of collaboration and identify future opportunities.

On the final day of the workshop a closed panel session was held to determine which of these opportunities would be supported. This condensed format was principally aimed at seizing on the immediacy of the opportunity to engage with Indian researchers.

A list of attendees can be found in appendix 1

1.2 Workshop Agenda

22 March

10:00 Tea/Coffee

10:30 Presentation – UK

10:45 Presentation – India

11:00 Workshop aims and process

11:15 Break into groups around themes

Session 1: Identification of Opportunities (delegates to highlight their areas of expertise and identify opportunities for UK-India collaboration around these areas)

13:00 Buffet Lunch

Session 2: Market Place (delegates to comment on ideas developed in session 1)

14:00 Groups

Session 3: Develop Activity (Break-out groups to develop activity proposal further)

16:00 Tea/Coffee Break

Session 4: Market Place (delegates to place final comments on proposals developed in session 3)

17:00 Round up and close for the day – What's happening in the evening/tomorrow.

19:00 Evening Meal

23 March

9:00 Welcome back

9:15 Back into groups

Session 5: Finalise Proposal

12:30 Closing Comments

13:00 Short visit by Minister Pat McFadden

13:15 Lunch

14:00 Delegates free to network

14:00 Closed Panel Session.

Mr Pat McFadden, Minister for BIS attended the workshop at the end of the second day to meet with the delegates and impress upon them the importance the Government places upon the international development of nuclear power as a clean and safe energy source and in particular the opportunities presented by closer collaboration between the UK and India in this and other areas.

1.3 FCO Nominated Experts

This workshop was a critical step to building understanding between UK and Indian civil nuclear researchers. Whilst India remains outside the NPT, she has recently signed nuclear agreements with the US, UK and other countries and has committed to separating strategic and civilian nuclear programmes over time. In order to provide a framework for UK researchers to openly discuss research opportunities two FCO nominated experts - one policy and one technical –attended the workshop. The FCO experts observed and discreetly advised academics where appropriate but were otherwise not involved in shaping the research proposals.

2.0 Peer review

UK Attendees to the workshop were invited based on previous track record with the research councils.

A panel of three members reviewed the developed proposals:

- Dr. Baldev Raj, Director, IGCAR
- Professor Richard Clegg National Nuclear Centre of Excellence
- Dr Andrew Worrall National Nuclear Laboratory

Prior to the closed panel session the workshop delegates were given the opportunity to "pitch" their developed proposals. The panel also had the opportunity to ask questions for clarification.

EPSRC facilitated the closed panel session and a technical advisor for the FCO sat in on the panel but did not take part in the peer review discussions.

A copy of the peer review form can be found in appendix 2, in summary the proposals were reviewed based on:

- Scientific excellence.
- How it builds on UK/Indian strengths.
- The opportunity to highlight UK/Indian capabilities to wider communities.
- Proposed mechanism to support both the UK and Indian exchange researchers.

As a final stage, where proposals were considered to be of equal value regarding the above criteria, the panel were asked to ensure that a breadth of likely networking opportunities was funded.

2.1 Panel Summary

Eleven outline proposals were developed for consideration at the panel (more details on these can be found in appendix 3). The panel considered each in turn and these are the summary comments.

2.1.1 Title: Validation and verification for critical heat flux and CFD

Quality:

Partly novel building on what they have done previously as part of the KNOO programme. Good to build on this. Methodology good. Adventurous in that looking to use large scale rigs. Will make a unique contribution to the science.
Excellence of this proposal has been demonstrated - Fully

Impact:

Pays to collaborate here. UK brings modelling – India experimental side. Will help CHF and CFD community world wide.
Potential impact has been demonstrated – Fully

Resources and Management:

Good. Builds on existing activities
Level of planning and justification of resources is – Good

Your Conclusions

Good synergy leading to new mechanistic understanding.

Overall Score - 5

2.1.2 Title: Advanced cladding materials and behaviour

Quality:

Novelty standard traditional materials good analysis not blue stays but important. Incremental but it is the kind of thing that is needed. Methodology is very good.
Excellence of this proposal has been demonstrated - adequately

Impact:

Appropriate beneficiaries. Clear route to exploitation - builds body of knowledge. Right impact area – collaboration in fuels important. UK India synergies not shown. Benefit is clear but it is not clearly building a unique linkage of expertise.
Potential impact has been demonstrated – adequately

Resources and Management:

Strong point as it integrates into existing programmes. If given the opportunity they could deliver. Definitely resourced correctly, it can all be done.
Level of planning and justification of resources is – Good

Your Conclusions

Good solid proposal. Crowded area. Based on application. Will lift baseline a little.

Overall Score - 4

2.1.3 Title: Minor actinide separations for reducing radio-toxicity of waste

Quality:

Novel proposal additional to existing processes. Already large scale programmes in this area, lots working on these areas. Difficult

science. Pursued for many years but answers not found. Good approach. Builds on existing programmes.
Excellence of this proposal has been demonstrated - Fully

Impact:

UK India additionality – yes has the right people. Can have good impact for relationships but exploitation/impact not likely to be realised. Proliferation issues need to be considered. India UK linkage very good. This is a very competitive field.
Potential impact has been demonstrated – Adequately

Resources and Management:

Realistic. Lots of experience in this. PDRA's - check as costs need justification. Access to lot lab with handling of curium – where? This is to done in India.
Level of planning and justification of resources is – Good

Your Conclusions

Good Science. Good UK India Link. Not sure about application side. Proliferation issues on international scale.

Overall Score – 5

2.1.4 Title: Irradiation effects on flow localisation in zirconium alloys

Quality:

Real world relevance. Erosion leads to localised corrosion/pitting. Good science – real adventure in mixture of approaches brought together.
Excellence of this proposal has been demonstrated - Fully

Impact:

Very relevant challenge. Multiple applications. Very good UK Indian collaboration.
Potential impact has been demonstrated – Fully

Resources and Management:

Right facilities at India/UK sites.
Level of planning and justification of resources is – Good

Your Conclusions

Clearly could form an area of long term collaboration. Good blend UK analytical with Indian irradiation capabilities.

Overall Score - 6

2.1.5 Title: Fuel cycle studies

Quality:

Good methodology. A lot of prior art in UK that has not been considered. Very broad. Science quality not demonstrated.
Excellence of this proposal has been demonstrated – Not at all

Impact:

Failed to reference and demonstrate increase over existing work
Potential impact has been demonstrated – Not at all

Resources and Management:

Fine
Level of planning and justification of resources is – Adequate

Your Conclusions

Overall failed to demonstrate additionality to existing understanding.

Overall Score - 3

2.1.6 Title: Understanding radiation damage effects in glass materials for HLW immobilisation

Quality:

Crowded field, there is a lot of work in this area. Adds a little but not a demonstrable step change. Comparisons very good – X use of techniques could add a lot. In UK novel as it is using radioactive glasses. Mechanistic knowledge would be very good
Excellence of this proposal has been demonstrated - Adequately

Impact:

Key area of strength in UK and complementary with that in India. India UK linkages very strong – added value shown. Publications could be excellent. Impact here on repository performance.
Potential impact has been demonstrated – Fully

Resources and Management:

Links well with analytical activities in Imperial. Good methodology.
Level of planning and justification of resources is – Good

Your Conclusions

Good area for lasting collaboration. Good science and application. Good team.

Overall Score - 5

2.1.7 Title: Advanced joining technologies

Quality:

Characterisation of bonds by new methods. Advanced processing and advanced characterisation methodology. Very good complementarity.
Excellence of this proposal has been demonstrated - Fully

Impact:

Excellent groups on both sides. Huge potential for an enduring relationship. Impact exploitable. Good uses outside of nuclear as well.
Potential impact has been demonstrated – Fully

Resources and Management:

Balance of post-doc and PhD very good. Resource appropriate and project deliverable.
Level of planning and justification of resources is – Good

Your Conclusions

Good area, good teams, exploitable and likely to be scientifically interesting enough to build enduring relationship.

Overall Score - 6

2.1.8 Title: Nuclear materials modelling – application to ODS

Quality:

Based on existing models and methods. This looks to apply them to a real world application. Application good but no cutting edge science. Studies will be done on Indian samples. Methods are good. Looking to apply to a difficult problem. Model validation – this is the quality part of the proposal, good chance too validate against a real world system.
Excellence of this proposal has been demonstrated - adequately

Impact:

Plays to the respective strengths of the UK and India therefore this is appropriate. Not a clear route for exploitation of model. Models don't work yet on basic steels - what chance for these? Would have been better as part of one of the other ODS proposals as they need this kind of modelling capability.
Potential impact has been demonstrated – Not at all

Resources and Management:

Good
Level of planning and justification of resources is – Good

Your Conclusions

Incremental – would have been better as part of one of the other ODS proposals

Overall Score - 3

2.1.9 Title: Determining Differences in the Performance of Thoria and Urania Based Fuels

Quality:

Not novel in some senses as this has been done for urania based fuels. Needs doing <u>but</u> data doesn't exist yet.
Excellence of this proposal has been demonstrated - Adequately

Impact:

Could and should have impact. If the intension is to develop thorium fuels you would need this data. Indian side does not have the tools to do this on their own.
Potential impact has been demonstrated – Adequately

Resources and Management:

Good
Level of planning and justification of resources is – Good

Your Conclusions

Good proposal but lacks evidence of existing information to support research elements.

Overall Score - 4

2.1.10 Title: Characterization of the microstructure, texture development and mechanical performance of ODS during and following thermomechanical processing

Quality:

Simulation and measurement of the effect of processing on the evolution of material properties. Novelty in bringing measurement and processing together to provide a predictive capability.
Excellence of this proposal has been demonstrated - Adequately

Impact:

Potential impact is high – predictive ability would have high impact. Relevant – application area could have significant impact. Good India UK collaboration (UK brings inspector techniques, India processing). Synergy between UK/India can make this a real winner. DIAMOND access is key.
Potential impact has been demonstrated – Fully

Resources and Management:

Modelling aspects are probably too far and wont be delivered. Mechanistic understanding could be delivered. Looks to be a bigger proposal that has been cut back too much.
Level of planning and justification of resources is – Unacceptable

Your Conclusions

Good proposal, Important area. Doesn't nail the challenge – needs to be bigger and has been cut back too much. Don't believe this proposal can deliver the level of modelling needed.

Overall Score - 3

2.1.11 Title: PDS Interfaces – Characterisation small scale ytum etc

Quality:

Novel approach. Excellent science
Excellence of this proposal has been demonstrated - Fully

Impact:

Brings together a wider network of people. Good synergies between India and UK. Materials India – Modelling and measurement UK. Unique facilities in UK.
Potential impact has been demonstrated – Fully

Resources and Management:

No issues, good
Level of planning and justification of resources is – Good

Your Conclusions

Excellent mix UK and India capabilities. Builds on key strengths.

Overall Score – 5

2.2 Proposal Ranking

Title	Grade	Value
Irradiation Effects on Flow Localisation in Zirconium Alloys	6	£320k
Advanced Joining Technologies	6	£310k
Validation & verification for Critical Heat Flux and CFD	5	£204k
Characterization of the small-scale structure of the yttria-based particles in ODS	5	£143k

Title	Grade	Value
Understanding radiation damage effects in glass materials for HLW immobilisation	5	£204k
Minor Actinide Separations for Reducing Radiotoxicity of Waste		£200k
Advanced Cladding Materials and Behaviour		£219k
Determining Differences in the Performance of Thoria and Urania Based Fuels		£202k
Fuel Cycle Studies		£243k
Nuclear Materials Modelling : Application to Oxide Dispersion Steels (ODS)		£199k
Characterization of the microstructure, texture development and mechanical performance of ODS during and following thermomechanical processing		£197k

The top 5 proposals were successful.

The scientific/technical quality of the proposals were high however where some failed to score was on the evidence of the bringing together of unique UK/Indian capabilities to form a linkage that would be sustained past the lifetime of the proposed project.

Appendix 1: Delegates

Indian Delegates

Dr. Baldev Raj, Director, IGCAR - Materials for fast reactors including welding and irradiation induced property changes

Dr. P. D. Gupta, Director, RRCAT (Developments in Nd-Glass Lasers and other high power laser activities)

Dr. B. Purniah, Head, ISD, DAE (Education and High end Facilities)

Dr. C. S. Sundar, Director, MSG, IGCAR (Radiation Damage & Modelling including ODS alloys)

Dr. G. K. Dey, Head, MSD, BARC (Materials for new generation reactors and Welding of dissimilar metals)

Dr. P. D. Krishnani, Head, RPDD, BARC (Reactor Physics of new reactors including thorium)

Shri S. Anantharaman, Head, PIED, BARC (PIE & Materials properties including safety analysis of fuels)

Dr. P.K. Vijayan, Head, Thermal Hydraulics Section, RED, BARC (Thermal Hydraulics and Reactor Safety)

Dr. B. S. Tomar, RCD, BARC (radiochemistry including optimised waste forms and transmutation and partitioning

UK Delegates

Prof Trevor Rayment, Diamond Light Source

Dr Matthew Eaton, Imperial College London
http://www3.imperial.ac.uk/people/m.eaton

Prof Bill Lee, Imperial College London
http://www3.imperial.ac.uk/people/w.e.lee

Prof Mike Lowe, Imperial College London
http://www3.imperial.ac.uk/people/m.lowe

Prof Robin Grimes, Imperial College London
http://www3.imperial.ac.uk/people/r.grimes

Dr Simon Walker, Imperial College London
http://www3.imperial.ac.uk/menuclearengineering/people/drsimonwalker

Prof Colin Boxall, Lancaster University
http://www.engineering.lancs.ac.uk/staff/?ID=184

Prof Malcolm Joyce, Lancaster University
http://www.engineering.lancs.ac.uk/staff/?id=46

Prof Roger Smith, Loughborough University
http://www-staff.lboro.ac.uk/~mars/

Prof John Bouchard, Open University
http://materials.open.ac.uk/staff/Staff_pjb.htm

Dr Martin Rist, Open University
http://materials.open.ac.uk/staff/staff_mr.htm

Prof Mike Fitzpatrick, Open University
http://materials.open.ac.uk/staff/Staff_mef.htm

Dr Brian Connolly, University of Birmingham
http://www.eng.bham.ac.uk/metallurgy/staff/connolly.shtml

Dr Chris Truman, University of Bristol
http://www.bristol.ac.uk/mecheng/people/person.html?id=17056

Dr Geoffrey Parks, University of Cambridge
http://www-edc.eng.cam.ac.uk/people/gtp.html

Dr William Nuttall, University of Cambridge
http://www.jbs.cam.ac.uk/research/faculty/nuttallw.html

Prof Andrew Sherry, University of Manchester
http://www.materials.manchester.ac.uk/aboutus/staff/andrewsherry/

Dr James Marrow, University of Manchester
http://www.materials.manchester.ac.uk/aboutus/staff/jamesmarrow/

Prof Simon Pimblott, University of Manchester
http://www.chemistry.manchester.ac.uk/aboutus/staff/showprofile.php?id=586

Prof Timothy Abram, University of Manchester
http://www.manchester.ac.uk/research/Tim.abram/

Prof Chris Grovenor, University of Oxford
http://www.materials.ox.ac.uk/peoplepages/grovenor.html

Dr Neil Hyatt, University of Sheffield
http://www.shef.ac.uk/materials/staff/nchyatt01.html

UK Panel Members

Professor Richard Clegg, NNCE

Dr Andrew Worrall, NNL

Other Representatives

Stephen Elsby, EPSRC

Sam Riches, EPSRC

Denise Dabbs, EPSRC

Sukanya Kumar-Sinha, RCUK Office in India

Richard Buttrey, FCO

FCO representative

Nuclear Consultant - MOD

Mr Rawat, HCI London

Appendix 2: Review Form

EPSRC
Polaris House, North Star Avenue, Swindon, Wiltshire, United Kingdom SN2 1ET
Telephone +44 (0) 1793 444000
Web
http://www.epsrc.ac.uk/

Indo UK Civil Nuclear Collaboration
Peer Review

Applicant Details

Applicants		Organisation	

Title of Research Project

Quality

Please comment on the degree of excellence of the proposal making reference to:
1. *The novelty, relationship to the context, and timeliness*
2. *The ambition, adventure, and transformative aspects identified*
3. *The appropriateness of the proposed methodology*

The excellence of this proposal has been demonstrated:

☐ Not at all	☐ Adequately	☐ Fully

Impact

Please comment on the extent to which the proposal shows the potential impact of the project, making reference to:

1. *The relevance and appropriateness of any beneficiaries or collaborators*
2. *Have all appropriate beneficiaries been identified (e.g. wider networking opportunities)*
3. *Whether appropriate routes and resources have been identified for dissemination and knowledge exchange*

Potential impact has been demonstrated:

☐ Not at all	☐ Adequately	☐ Fully

Resources and Management

Please comment on the effectiveness of the proposed planning and management and on whether the requested resources are appropriate and have been fully justified.
Have appropriate support mechanisms for exchange researchers been identified.

The level of planning and justification of resources is:

☐ Unacceptable	☐ Adequate	☐ Good

Overall Assessment

Your Conclusions

Please summarise your view of the proposal.

My judgement is that:

1 - This proposal is scientifically or technically flawed

2 - This proposal does not meet one or more of the assessment criteria

3 - This proposal meets all assessment criteria but with clear weaknesses

4 - This is a good proposal that meets all assessment criteria but with minor weaknesses

5 - This is a strong proposal that broadly meets all assessment criteria

6 - This is a very strong proposal that fully meets all assessment criteria

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

Appendix 3: Details of development of proposals

Opportunity title: Validation & verification for Critical Heat Flux and CFD

Dr. P.K. Vijayan- BARC
Dr S P Walker- Imperial

Statement of Opportunity:

Plainly, thermal hydraulics is a major area of research, vital to nuclear reactor analysis and safety, and one that will probably remain vital for as long as we have nuclear power. Of necessity, we have focussed in this proposal on two aspects only; both important, but only a small subset of the work that one could consider. We would in part see this project as providing an entre for collaboration which we would then wish to see broaden and deepen.

Computer codes are obviously used to support nuclear safety cases, and these plainly need to be soundly based, on well verified correlations and models. The coupled areas of fluid flow in general, and the particular, crucial fluid flow phenomenon of critical heat flux, are ones where sound experimental justification of the models are vital.

Both parties have a strong interest in trustable CFD simulations of nuclear systems, especially for safety analyses. With fellow consortium members, Imperial leads a grant focused on computational nuclear thermal hydraulics modelling, under which V&V of nuclear CFD is a major component. This consortium has a very strong thermal hydraulics modelling capability within its academic members and with its industrial collaborators, which include major CFD developers. BARC has extensive and sophisticated major experimental rigs, with a rich capability to make measurements, and a rich set of existing measurements.

Together these two groups have the capability to add a great value, by working together to establish and analyse challenging test cases, to analyse these using advanced CFD methods, and to establish error bounds, sensitivities and modelling requirements.

BARC has extensive and sophisticated facilities for measurements of critical heat flux and associated parameters. It has an active programme in this area, and is about to undertake a further range of CHF and associated experiments (high & low pressure, low and high flow (natural circulation & forced), with tube & bundle geometries.

UK (Walker, Hewitt & colleagues) have both current research activities and unparalleled expertise in this area, but the UK now lacks experimental facilities. Collaboration here would add great value, allowing the expertise of the Imperial group to be brought to contribute to the experiment design, interpretation and analysis of the BARC experiments. The combination will allow overall greater value to be gained, improving understanding and quantification of these important issues.

Opportunity title: Advanced Cladding Materials and Behaviour

Lead Contacts:

Shri Anantharaman – BARC
T J Abram – Manchester
R W Grimes – Imperial
M Preuss – Manchester
M Fitzpatrick – Open
J Marrow - Manchester

Statement of Opportunity:

Zirconium-based alloys have demonstrated very good performance in water cooled reactors, and their use is widespread. The deformation mechanisms associated with Zr-based claddings under severe accident conditions are of great importance in ensuring the safety of nuclear plants, but a fundamental understanding of these mechanisms remains to be fully developed. An opportunity therefore exists to study the high-temperature and high strain-rate deformation mechanisms associated with Zr-based claddings, especially with regard to ballooning behaviour under dry-out conditions. Of key importance will be an investigation of the effects of texture, and its development during thermal and mechanical processing of the cladding.

For the future, scope for further optimisation of Zr-based claddings may be limited, and alternative materials may offer the potential for significant improvements in steady-state and transient conditions. Both sides are interested in identifying potential new materials for application as cladding, which are capable of providing:

- An effective barrier against fission product release;
- Maintaining structural integrity under accident conditions;
- A low thermal neutron capture cross section;
- Chemical compatibility with the fuel material and with the coolant.
- Acceptable thermal properties.
- Compatible with potential a reprocessing route or long-term storage.

Opportunity title: Minor Actinide Separations for Reducing Radiotoxicity of Waste

Investigators:

Colin Boxall- Lancaster
Simon Pimblott- Manchester
B.S.Tomar- BARC
Trevor Rayment- Diamond Light Source

Named Collaborator:

Neil Hyatt- University of Sheffield

Statement of Opportunity:

Separation of irradiated nuclear fuels is an essential component in the expansion of options for nuclear waste management. The partitioning of the highly radiotoxic minor actinides (MAs) from high level liquid waste (HLLW) prior to its disposal, and the subsequent transmutation of those MAs is currently attracting interest worldwide due to its potential to:

- Reduce the quantity and radiotoxicity of HLW bound for geologic disposal.
- Enable more effective use, and so reduce the cost, of geologic disposal.
- Underpin the development of GenIII+ and GenIV nuclear energy systems.

India and the UK have interests in the application of solvent extraction-based separations in this area, the latter most notably through the recent establishment of the EPSRC-funded MBASE (Molecular Basis of Advanced Nuclear Fuel Separations) consortium (Manchester, Lancaster, Reading, Imperial, NNL). This, and the availability of the expertise and active facilities at BARC (Bhabha Atomic Research Centre, Mumbai) with the capability of handling the most radiotoxic of the MAs (Cm), presents an opportunity for us to propose a joint India / UK project with the aim of making a step function change in understanding mechanisms of key MA partitioning processes, so supporting flow sheet development for reducing the radiotoxicity of high level waste. This will be achieved through understanding of the structural chemistry, radiation stability thermo-dynamics & kinetics of MA solvent extraction processes and the complexes formed therein.

This is a two year project to be performed by a UK-based PDRA co-supervised by the Universities of Lancaster and Manchester, with a 4/5 month period of placement at BARC (months 18-23) and an Indian supported PDRA, with a 3 month period of placement in the UK (months 1-4)

Background

Current large scale separations of irradiated nuclear fuel are generally based on the Purex (Plutonium-Uranium Extraction`) solvent extraction process, a 50 year old technology, originally developed to separate a pure Pu stream from lightly irradiated fuel. Modern uranium fuels for civil reactors have a much higher burnup, resulting in increased minor actinide (Np, Am, Cm) contents and much more intense radiation fields.

MA control is widely perceived as becoming important in support of higher burn up fuels (medium term) and GenIV reactors (long term). The associated higher heat loads and alpha content will present new challenges to waste management. One solution is to use solvent extraction methods to partition the MAs from the HLLW stream prior to disposal to repository. The partitioned MAs are then incinerated / transmuted either within a fast breeder reactor or an accelerator driven system (ADS). Such partitioning offers substantial benefits in the areas of waste form and repository design, resulting in lower radiotoxicity, heat load and volumetric burdens for the repository and reduced radiation damage to the waste form itself.

MA separation by solvent extraction is not trivial and presents a number of problems, especially in the areas of actinide/lanthanide discrimination, solvent loading capacity (and associated third phase formation and criticality issues) and the requirement of greater radiolytic resistance of both extractant and diluents (solvent).

More recently, Purex-type processes have been extended to recover MAs from the aqueous Highly Active Raffinate (HAR) e.g. through Diamex/Sanex in India and Europe (using malonamide, diglycolamide and BTBP based ligands) or Truex/Talspeak in the US (using CMPO and HDEHP/DTPA). Whilst Purex is widely regarded as a mature technology, there are substantial challenges and knowledge gaps with respect to these advanced separations. In the case of the former, separation of the MAs from the chemically similar fission product-derived trivalent lanthanides is a major issue. In the case of the latter, basic chemical kinetic and thermodynamic data is required to support flow sheet development, especially complex structures and stability constants, mechanism & kinetics of extraction, radiolytic stability, distribution ratios and separation factors. There is substantial interest in both India and the UK in the provision of such data for Np, Am and Cm, there being a particular paucity of information relating to Cm. Given the BARC capacity to work with Cm, its expertise in radiation & radiochemistry, and the recent funding by EPSRC of the £1.3 million MBASE project to obtain said information for, inter alia, the Am-BTBP system there is here a unique opportunity to develop MA separations for highly radiotoxic curium.

Opportunity title: Irradiation Effects on Flow Localisation in Zirconium Alloys

Lead Contacts:

TJ Marrow – Manchester
S Pimblott – Manchester
J Fonseca – Manchester
M Preuss – Manchester
S Roberts – Oxford
GK Dey – BARC
S Anantharaman - BARC

Statement of Opportunity:

Project 1

Effects of Irradiation on Materials Degradation:

The effects of intense radiation fields present in most reactor environments lead to problems with long-term operation of materials. The effects are particularly significant on the microstructure and mechanisms of deformation. This has knock-on effects on degradation mechanisms such as creep, fatigue, stress corrosion etc, through processes such as localisation of plastic strain and dislocation behaviour (i.e. flow localisation).

A central theme of this proposal is the use of ion irradiation to simulate irradiation damage, and to validate this against neutron irradiation, in order to understand the predict materials degradation. There is also interest in the possibility of in-situ monitoring for the effects of irradiation on microstructure and degradation. Central facilities are important for the study of these processes.

Cross-cutting themes:

- Fundamental science
- Irradiation effects
- Microstructural characterisation
- Multi-scale modelling
- Numerical simulation

Opportunity title: Fuel Cycle Studies

Lead Contacts:

Prof. P.D. Krishnani – BAR
M.D. Eaton – Imperial
W.J. Nuttall – Cambridge
G.T. Parks - Cambridge

Statement of Opportunity:

With special emphasis on Thorium

Open/Closed Cycle

Seeking greater proliferation resistance

Case studies of PWR (benchmark), PHWR, HTGR, ADSR

Increase initial conversion ratio

Safety characteristics

Economic appraisal

Metrics for proliferation resistance

Impact on repository performance (feedback to fuel design)

Sealed/full-lifetime cores

UK modelling studies (impact of data libraries ENDFB7, JENDL3.2)

India experiments at BARC

Data assimilation of integral measurements

Opportunity title: Understanding radiation damage effects in glass materials for HLW immobilisation

Investigators:

N.C. Hyatt – Sheffield
W.E. Lee – Imperial
B.S. Tomar – BARC
C.P. Kaushik BARC
T. Rayment- Diamond Light Source.

Named collaborators:

I. Farnan- University of Cambridge.

1. Objectives:

Executive summary. The overarching objective of this proposal is to initiate an India-UK collaboration to lead development of understanding of radiation damage processes in nuclear waste glasses and glass composite materials (GCM's) containing crystals. UK collaborators will contribute in two principal areas: provision of expertise in application of X-ray spectroscopy methods to radiation damaged materials and application of advanced analytical electron microscopy to glass and glass composite characterisation. Indian collaborators will bring many years of expertise in preparation and characterisation of radionuclide-containing nuclear glasses by electron spin and positron annihilation spectroscopies. This project will access world class central laboratories for materials irradiation (in India) and synchrotron radiation (in the UK). The outcome of this collaboration will be to provide the fundamental understanding required to develop predictive models for performance of radiation damaged glasses and GCM's in geological disposal facilities.

Vitrification of high level waste (HLW) from reprocessing is common to both the fuel cycle in the UK, India, and elsewhere. Furthermore, both countries have Cold Crucible Melting Facilities under development for some difficult wastes which will produce glass composite wasteforms. The glass matrix constitutes the first barrier to radionuclide release and dispersion in the disposal environment. Importantly, glass dissolution rates are known to be sensitive to accumulation of radiation damage but the microscopic origin of this behaviour is unclear. Furthermore, the impact of radiation damage on crystals and glass in GCM's has not been examined. **Through systematic investigation, this proposal aims to develop a fundamental understanding of radiation damage on the physical and chemical changes in model HLW glasses and GCM's at both the atomic and macroscopic scales.** Such understanding is crucial to accurate modelling and prediction of glass performance under disposal conditions, over geological timescales, particularly in the absence of natural geological analogues for nuclear waste glass compositions.

The objectives of this proposal are:

1. To understand and quantify the effect of radiation damage on glass, glass-crystal interface and crystal stability in glasses.

2. To understand the effect of radiation damage on glass, glass-crystal interface and crystal structures and radionuclide speciation.

3. To understand and quantify the effect of radiation damage on glass and GCM durability.

4. To enable reciprocal knowledge transfer and large facility access through mobility of personnel.

5. To develop a sustainable platform for the purpose of mutually beneficial collaboration.

Our investigation will involve systematic radiation damage studies on carefully selected glass and GCM compositions to develop the first comprehensive understanding of the effect of radiation damage on glass and crystal-containing glass stability, structure, and durability.

Since this project is related to proliferation sensitive aspects of the fuel cycle, we undertake to notify appropriate licensing authorities in BIS and FCO, on notification of funding award.

Opportunity title: Advanced Joining Technologies

Lead Contacts:

Dr G. K. Dey (BARC)
Dr T. Jayakumar – IGCAR
Dr A K Bhaduri – IGCAR
Professor J Bouchard - Open
Dr C E Truman - Bristol
Professor A H Sherry – Manchester
Professor. M Lowe - Imperial

Statement of Opportunity

Advanced joining technologies, including solid state diffusion bonding, laser hybrid welding, friction stir welding, electron beam welding (low vacuum) and narrow gap arc welding are critical for the safe operation of existing plant, and the optimised design of future reactor systems. Of particular challenge are new joining techniques for dissimilar materials in advanced nuclear power plants.

The aim of this project is to establish a strategic long-term Indo-UK collaboration “JOINT” that is aimed at identifying and optimising joining technologies for specific nuclear components. The project will draw on existing capabilities and programmes within UK academia (Open University, Bristol, Manchester Universities and Imperial College, London) and the Indian DAE Research Centres of BARC and IGCAR. The project will link strongly with the UK’s Nuclear Advanced Manufacturing Centre (Sheffield, Manchester) thereby providing a route to exploitation, the UK Research Centre in non-destructive evaluation (RCNDE), and the UK’s National Nuclear Centre of Excellence. These organisations are all strong networks of academic and industry partners.

JOINT will pioneer new and advanced joining technologies by optimising fabrication parameters, microstructures and properties for the reliable performance of a variety of metallic and non-metallic material joints of relevance to present and future reactor systems. Such optimisation will require among other things narrow heat affected zones, low residual stress, strain and distortion with minimum and quantifiable risk of joint defects. Developments will draw on advanced experimental methods to characterise joints, and modelling approaches to simulate and predict joint characteristics.

The JOINT consortium brings together partners of international reputation who are at the forefront of joining technologies for example laser hybrid welding, diffusion bonding, electron beam, narrow gap TIG, NDE, modelling, and have a proven track record of access to high-end national and international facilities relevant to the project, e.g. ISIS, DIAMOND, ILL etc.

The unique opportunities provided by the JOINT consortium are the complementary nature of India's joining technology expertise and the UK's weld characterisation expertise.

Opportunity title: Nuclear Materials Modelling: Application to Oxide Dispersion Steels (ODS)

Lead Contacts:

Roger Smith – Loughborough
C.S. Sundar - IGCAR

Statement of Opportunity:

ODS materials are promising candidates for future nuclear reactor pressure vessels because of their radiation resistance and their ability to limit the growth of inert gas bubbles generated by nuclear reactions. Modelling provides a unique way to investigate these materials. This provides the basis of a project with complementary expertise. The UK has a long tradition of modelling associated with radiation effects and materials properties, whereas India is arguably ahead of the UK in its experience with the new types of radiation resistant ODS materials.

This will allow UK expertise in ODS materials to be improved and Indian capability in modelling of nuclear materials and radiation events also to be significantly developed.

Opportunity title: Irradiation Effects on Flow Localisation in Zirconium Alloys

Lead Contacts:

Opportunity title: Characterization of the small-scale structure of the yttria-based particles in ODS

Lead Contacts:

Chris Grovenor – Oxford
C S Sundar - IGCAR

Statement of Opportunity:

Nanoscale chemistry and structure dominate the performance of ODS alloys, but we do not fully understand:

- When the dispersions are generated during thermo-mechanical processing
- What the interface chemistry and atomic structure is
- What effect this interface has on absorbing the products of irradiation

- How best to integrate modelling to help understand both fabrication mechanisms and radiation resistance.

Even with this lack of a full understanding, ODS alloys are expected to play an important role as structural materials in future generations of nuclear reactors.

Using fabrication expertise in India and characterisation expertise in both countries, there is a clear, timely opportunity to design a programme of work to explore the fundamental metallurgy of these alloys with the aim of designing new alloys with improved properties.

Opportunity Title: Characterization of the microstructure, texture development and mechanical performance of ODS during and following thermomechanical processing

Lead Contacts:

Martin Rist – Open
Mike Fitzpatrick – Open
Chris Grovenor – Oxford
C. S. Sundar – IGCAR
T. Jayakumar - IGCAR

Statement of Opportunity:

ODS materials show enhanced high-temperature creep resistance and low irradiation swelling, making them candidate materials for future generation fission plant.

ODS materials have mainly been characterized without secondary processing, and not in a final product form. For use as fuel cladding tubes, they will require low crystallographic texture to ensure isotropy and minimize creep deformation.

The opportunity is to combine the expertise in India on the fabrication of ODS and its processing into final product form, with UK expertise in modelling and measurement of microstructure evolution and texture development during thermomechanical processing, combined with *in situ* neutron diffraction experimentation of texture development during deformation at temperature.

The UK team, led by the OU, has expertise in the deformation mechanics of metallic materials, microstructural analysis, and texture measurement. In particular the OU group has strong expertise in the application of neutron diffraction, including *in situ* deformation for monitoring the development of texture and intergranular stress.

The Indian team, based at IGCAR, has expertise in the fabrication and secondary processing of ODS alloys, microstructural characterization, and texture analysis.

The programme will build a collaboration to exploit the synergies between the OU and IGCAR groups, and will link to complementary programmes including a programme grant at Oxford and a recently-funded Nuclear Fission consortium, looking at the fundamental mechanisms of particle and interface development and the role of the precipitates in ODS alloys. This programme will provide insight into the effects of the dispersion and grain structure on deformation characteristics, and on segregation and morphological changes of dispersoids during thermomechanical deformation. The particular focus will be on the high-Cr ferritic systems which do not develop a martensitic structure following heat treatment and where the texture development is consequently more severe.

The intention is to understand how the process history affects the final texture, microstructure, and mechanical behaviour of the material.

Extensions of this initial opportunity would include measurement of the effects of texture on creep behaviour, response to irradiation, and how prior process history influences the performance of the material following joining.

Opportunity title: Determining Differences in the Performance of Thoria and Urania Based Fuels

Lead Contacts:

T J Abram – Manchester
R W Grimes – Imperial
Shri Anantharaman – BARC
K. B. Khan -
M Joyce - Lancaster

Statement of Opportunity:

There is considerable concern that uranium reserves are not sufficient to facilitate nuclear new build on a large scale. Thoria is around four times more abundant than urania, and could offer a potential alternative fuel cycle. While the performance of urania fuel cycles have been extensively investigated over many decades, there has been considerably less experimental and modelling work on the performance of thoria-based fuels. Current fuel modelling codes are based on semi-empirical relationships derived in part by fitting to available experimental data. Thus, codes for thoria are not able to predict fuel behaviour to the extent required for civil nuclear. Furthermore, whilst the performance of models has so far been adequate for urania, future fuel duties are likely to extend beyond the currently available experimental data-base. This is especially true for thoria-based mixed oxide fuels, where high burnups are anticipated to facilitate better utilisation of natural uranium. Significantly, further experimental work is both expensive and time consuming. It is therefore highly desirable to use modelling to inform experimental efforts, thereby reducing the burden of future experimental work. In addition, modelling can identify the underlying physical processes responsible for fuel performance and hence extend the validity of physically-based models. It can also support the investigation of severe accident conditions that are currently beyond the capabilities of current experimental facilities, and also to highlight the critical features of the underlying physical processes that need to be simulated and validated using future experimental facilities.

India is the world leader in the development of thoria-based fuels for civil heavy water reactors and intends to use thoria-based fuels in light water reactors. Within India the fuel development work is being carried out at BARC by the Indian partners of this proposal. The UK partners of this proposal have been developing the underpinning science and generating parameters for urania based light water reactor performance codes via their strong links with industry.

We note the complementarity of the ideas described here with a proposal entitled **Sustainable thorium fuel cycles with enhanced proliferation resistance**. We are pleased to indicate that if the peer reviewers so prefer, we would be happy to see our proposal amalgamated with the other bid to form a larger collaborative effort facilitating broader networking.