Memorandum of Understanding (MoU)

Between

Government of India
Board of Research in Nuclear Sciences,
Department of Atomic Energy (DAE);
Bhabha Atomic Research Centre,
Mumbai-400 085

And

Government of India
Bhabha Atomic Research Centre,
Department of Atomic Energy (DAE);
Mumbai-400 085

And

Indian Institute of Technology, Kharagpur

For

"Establishment of an Advanced Research Facility For EB Welding and Process Development Related To Programs of Interest to DAE"

Year 2006

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Between
Board of Research in Nuclear Sciences, Department of Atomic Energy (DAE),
And
Bhabha Atomic Research Centre, Department of Atomic Energy (DAE),
And
Indian Institute of Technology, Kharagpur
For
"Establishment of an Advanced Research Facility for EB Welding and Process Development Related to Programs of Interest to DAE"

This MoU is entered into this _____day of _____ 2006 between Board of Research in Nuclear Sciences of Department of Atomic Energy (DAE) [hereinafter called BRNS which expression shall include its successors-in-interest and assigns] situated at Trombay, Mumbai-400 085 on the **First Part,**

Bhabha Atomic Research Centre (BARC) situated at Trombay, Mumbai-400 085 (hereinafter called BARC which expression shall include its successors-in-interest and assigns) on the **Second Part,**
And

Indian Institute of Technology, Kharagpur [hereinafter called IIT- KGP] which expression shall include its successors-in-interest and assigns] on the **Third Part.**

PREAMBLE

Whereas the Board of Research in Nuclear Sciences (BRNS) is an Apex Body of the Department of Atomic Energy (DAE) for promoting collaborative R&D activities in the areas of interest to DAE and also for developing high quality technical and scientific manpower required for the various programmes undertaken by DAE. BRNS also support and encourage, academic institutions/universities/national laboratories in promoting interactions through symposia leading to the formulation of Research and Development activities in areas related to the mandate of the DAE.

Whereas BARC is a premier multidisciplinary R&D organisation under the Department of Atomic Energy, Govt. of India, engaged in research with the objective of generating knowledge and techniques for nuclear power production, advancement of science, use of radioisotopes in industry, health and agriculture as well as research in frontier areas of science and technology. BARC has groups of experts and have developed a number of sophisticated instruments and processes, which are of multi-disciplinary nature. One such activity spanning four decades is the development of Electron Beam (EB) technology suitable for thermal applications such as welding, melting and evaporation. It has supplied a number of such systems to various users within DAE and outside DAE. A list of units developed by BARC is given in **Annexure - I.** In the EB welding applications, BARC has not only contributed to the development of systems but also developed EB weld process for various metal and alloy combinations. It has provided welding solutions for users both within and outside DAE. Some of the jobs carried out by BARC are enumerated in **Annexure - II.** **In order to catalyse further development of the Science, Technology and to promote development of adequately trained HRD in this important technology regimen, as well as to prepare the ground to take up the major challenging EB Welding tasks associated with the ongoing and future programmes of DAE (accelerators, ADSS etc.), BARC felt it essential to establish an Advanced Research Facility for EB Welding and Process Development in an Institution that provides a conducive ambience for academic as well as R&D Activities.**

Whereas IIT-KGP is one of the foremost academic institutions in India, and has all necessary infrastructure in terms of trained manpower (including students), access to computational resources

and a long tradition of research and development. There is a ready pool of experts available at IIT-KGP in the field of welding, metallurgy, materials Science, production processes and vacuum engineering meeting the high standards expected by BARC/BRNS to fulfill the requirement of the objectives of the MoU.

Whereas BARC is desirous of availing the expertise and services of IIT-KGP for the eestablishment of an **Advanced Research Facility for EB Welding and Process Development, dedicated to** application oriented research (as detailed in Section 2 and 3 under the Heading Objectives **and Scopes of Work)** to provide **systematic scientific, technical and HRD inputs** to programs of interest to DAE and IIT-KGP has agreed to do the same. It has been agreed by all the three parties that the budget allocation for the design, development, procurement, installation and commissioning of the Electron Beam Welding Machine will be provided by BARC. The budget allocation under the headings staff salaries, technical assistance and consumables, contingencies and overheads will be made by BRNS. Now the above three parties agree to enter into an MoU as follows:

1. This MoU supersedes all previous correspondences and discussions in the matter.

2. OBJECTIVE:

Establishment of an **Advanced Research Facility for EB Welding and Process Development consisting** of an 80 kV, 12 kW Electron Beam facility for studies related to EB welding of metals and super alloys and demonstration of sample product welding of components of interest to DAE. In the first phase of the project (to be counted as 3 years from the date of registration of the project with SCRIC, IIT-KGP) development of welding process for superconducting Niobium Cavities required for various accelerator programmes of DAE will be taken up. **The exact scope of research activity would include welding process development, characterization of weldments including microstructures, numerical simulation of weld dynamics, development of predictive tools and their validation.** On successful completion of phase I of the project other component specific welding process development for metal systems like Zircaloy and Maraging steels will be taken up. At a later stage the facility would be used for exploring EB assisted cladding processes. **This facility when fully functional will be used to carry out suitable welding jobs/undertake development work for meeting the requirements of the DAE units as well as to develop an extensive database for specialized welding and surface engineering applications of EB Technology which are of interest to DAE.**
In addition, BARC and IIT-KGP would use this facility for generating high quality trained HRD for meeting the EB Technology requirements associated with the various development programs of DAE.

3. SCOPE OF WORK

The scope of work under the MoU shall be as detailed below.

3.1. Design, fabrication, procurement, installation and commissioning of an Electron Beam Welding Machine with the following specifications.

- EB Gun: An EB gun of capacity 80 kV / 12 kW would be installed capable of welding up to 10 mm thick copper.
- Work Chamber: A chamber size of 600mm x 600 mm x 800 mm would be installed
- Vacuum System: A vacuum system for the gun and work chamber would be designed to achieve a vacuum level of 3×10^{-6} mbar in the EB gun chamber and 1×10^{-5} mbar in the work chamber. The pump speed would be designed to achieve the required vacuum levels in the gun and work chamber within 1hour from cold start of the vacuum pumps.
- Work handling system: A 3- axis motion controller would be designed to carry a payload of 100 kg. The travel length in X- axis would be 200 mm. The travel length in Y-axis would be 200 mm. The system would be designed to achieve the required co-ordinate position within 50 μm.

3.2. Systematic study of the welding process for similar and dissimilar metals and super alloy systems of interest to the nuclear fuel cycle.

The study of EB welding of the following metals and alloys is of interest to various DAE programs

a. Niobium to Niobium	Superconducting Cavities for accelerator programs of DAE
b. Zircaloy to Zircaloy	Nuclear Fuel Cycle components
c. Zircaloy to stainless steel	Nuclear Fuel Cycle components
d. Maraging steel to Maraging steel	Nuclear Fuel Cycle components

However, considering the scope of work and the period of MoU, the systems at items (a) and (b) will be taken up for detailed study and data generation, resulting in successful development of welding procedures and qualified welding of sample Niobium Cavity during the first phase. The Maraging steel and dissimilar metal welding at items (c) & (d) will be taken up later.
Sufficient quantity of sample Niobium cavity together with the welding fixture is to be made available to IIT KGP by the user unit of DAE.

3.3 Systematic study referred to as above will consist of the following work components:

- Welding of the specified samples and weld characterization in terms of physical and metallurgical properties (refer **Annexure- III**).
- Monitoring and validation of the welding process.
- Establishing weld microstructure-property relationships through predictive codes to determine weld properties from knowledge of compositional and process parameters at room temperatures (refer **Annexure- IV**).
- Development of computer simulation of the welding pool (refer **Annexure- V**)

3.4 Generation of Database aimed at facilitating EB welding at BARC:

- IIT-KGP would generate welding database applicable within the limitations of the machine on the above systems and supply it to BARC.

3.5 DAE Jobs:

- Welding jobs that are of dimensions commensurate with the capacity of the Facility will be taken up as and when required by DAE.

3.6 Training of Manpower:

- HRD is an important component of this MoU. Efforts would be made to involve and train students as well as researchers in EB Technology. As and when necessary, researchers from the facility would work in collaboration with the BARC group at BARC. The facility will be used to initiate research projects for BARC engineers to work in collaboration with IIT-KGP faculty. **Short term training programme modules on electron beam welding process and applications will be designed and offered** for academic institutes and industry.

3.7 EB assisted Surface Engineering:

- Using the same facility for surface Engineering applications i.e. EB assisted cladding for thermal Barrier and corrosion resistant applications will be part of the extended future scope of this facility.

4. PERIOD OF MoU AND ITS EXTENSION

This MoU comes into effect from the date of its signing and will remain in force for five years or until the termination of the project. The initial sanction will be for three years. Its validity shall be extended based on the recommendations of the User Committee and by mutual agreement between the parties, so that the various short and long term objectives of this MoU are served satisfactorily.

5. DELIVERABLES

The facility will be used by BARC and other DAE Units as well as by IIT-KGP to generate the following deliverables:

5.1. Design, development and commissioning of the 80 kV/12 kW EB welding machine at IIT-KGP as per the plan of implementation listed in Section 6 of this MOU.

5.2. Analysis of weldability, weld characterization, experimental data and optimization data for product specific welding of similar as well as dissimilar metals and super alloys as specified (in order of priority) in Section 3 of this MoU. The first phase of the project will target the super conducting cavities required by DAE.

5.3. Development and validation of Predictive codes for evolving weld characteristics – process parameter correlation for metal systems as specified (in order of priority) in Section 3 of this MoU

5.4. Development of welding procedures and welding of components for DAE Units those are placed in the neighborhood of IIT-KGP and are of dimensions commensurate with the capacity of the Facility as per recommendations of the User Committee constituted under this MoU.

5.5. Submission of joint (IIT-KGP and BARC) quarterly progress reports covering the progress made on critical stages and objectives of the facility, highlighting the results.

5.6. Consolidated lecture notes of the short term training modules conducted under this programme will be provided to BARC.

5.7. A consolidated data base and report detailing the technical work will be submitted at the end of the Third Year of the MoU period. For the subsequent period, the User Committee constituted under this MoU shall submit an Annual Report to BRNS. And necessary mechanism for the continued utilization of the Facility beyond the third year shall be worked out by IIT-KGP in consultation with BARC and BRNS. Such a mechanism, as envisaged in the Objectives of this MoU, shall be formulated to facilitate sustainability and smooth rendering of services by this Facility to the DAE Units.

6. MODE OF IMPLEMENTATION:

The mode & implementation of this project will involve the following steps as indicated in the **Table 1.**

6.1 Technical Project Report:

- The Technical Project Report will consist of the following:
- Description of the parts of the EB gun column. The mechanical fabrication drawings would be appended at the end of the section.
- A specification of the power source required to energise the EB gun would be detailed.
- The mechanical and electrical specification of a 3-axis work handling system would be mentioned.
- The design drawing of the work chamber would be given.
- A line drawing of the vacuum system with details of the pumps and valves would be enumerated. The electrical specification of the vacuum controller would also be included in this section.
- Acceptability tests for the sub systems as well as the EB welder.
- Auxiliary system requirement (water / power / compressed air) and on site civil works required would be enumerated.
- Details of the targeted end products for the first phase and technical specifications of the qualification norms.
- Product derived guidelines on the materials that would be welded and weld qualification criterion would be mentioned.
- Details of the technique to be used for code development, solution procedures including inputs to and out puts from the respective codes.
- Details of samples to be welded, welding standards, physical as well as metallurgical properties to be determined with characterisation techniques to be used.
- Welding of sample product, cavities in the first phase, and demonstration of the machine capabilities.
- Details of monitoring and diagnostics experiments including hardware and software.
- Details of the projected database on the specified material. This would include structure, format and extent.

6.2 Manufacture of EB Welder

- The subsystems of the EB Welder would be fabricated as per the specifications mentioned in the Project Report. The vendors for the various sub-systems would be finalized by BARC and will be briefed to IIT-KGP. Both IIT-KGP and BARC personnel would work in close collaboration for all ensuing technical discussions, stage-wise inspection and the final inspection of the

various EB welder sub-systems.

6.3 Plan of Installation / Commissioning

- The vendors would carry out the installation/ commissioning of the various sub-systems. IIT-KGP and BARC personnel would inspect / supervise such work. Any persons / helpers required for this activity of temporary nature would be arranged by IIT-KGP. The vendors would not be responsible for weld trials.

6.4 Plan of Weldability Trials

- BARC personnel would carry out initial beam/ weld trials conforming to the acceptability test mentioned in the Project Report. BARC personnel would sort out problems if any in presence of IIT-KGP personnel, before formally handing the EB system to IIT-KGP for weld trials. IIT-KGP would carry out the weld trials as mentioned in the Project Report.

6.5 Plan of Experiments and Development of Simulation Code

- The plan of experimental and simulation work will be discussed by the working group on both sides and detailed in the technical report. The plan for welding dummy products made in some surrogate materials will also be discussed and a roadmap will be drawn in achieving the qualified welding of the end product. Data from weldment characterisation would be used to validate the numerical simulation of weld dynamics that would be initiated at IIT-KGP immediately. The proposed soft predictive model code is envisaged to correlate the process parameters to the weld characteristics.

6.6 Milestones

- The milestones for **three calendar years from start of work** have been worked out with realistic figures of time and presented in **Table 1**

Table 1 Schedule of Activities under the MoU

Sl. no.	ACTIVITY	QR I	QR II	QR III	QR IV	QR V	QR VI	QR VII	QR VIII	QR IX	QR X	QR XI	QR XII
1	Preparation of detailed technical specifications for tendering by BARC in consultation with IIT, KGP.	X											
2	Preparation of detailed technical specifications for software development and experimentation	X	X										
3	Staff recruitment	X			X								
4	Training of IIT-KGP faculty and staff in carrying out welding and familiarization with the machine at BARC	X	X			X							
5	Code development in weld dynamics	X	X	X	X	X	X	X	X				
6	Placing of Purchase order and procurement of various sub-systems of the welding machine by BARC in consultation with IIT, KGP		X	X	X	X							
7	System Integration at IIT-KGP and Commissioning (jointly by BARC and IIT, KGP)						X	X					
8	Weld trials and experiments on welding of Niobium (specific to the end product) and Zircaloy								X	X	X	X	
9	Welding characterization								X	X	X	X	
10	Validation of codes with experimental Data									X	X	X	
11	Optimization of Operating regime for best weld characteristics and demonstration of the facility in successful and qualified welding of the end product											X	X
12	Data base generation and reports												X
13	Use of the machine for EB cladding	**Future Scope**											

7. ROLE AND RESPONSIBILITIES OF BARC

BARC team would be mainly responsible for design, fabrication, installation and commissioning of the EB facility at IIT-KGP. In addition, BARC will be available for trouble shooting, training of the staff, collaboration on code development and diagnostics etc. A year wise break up is provided below.

Ist Year:

- Identifying the products of interest and their welding layouts. Establishing user defined qualification norms.
- Design of the subsystems of EB Facility: The subsystems include, Work chamber and work handling system, Vacuum system, EB power source and controls, E gun and focusing column. A Project Report will be prepared.
- Testing of the subsystems at vendor's site before dispatch. E gun and focusing column will be delivered at BARC and tested before shipping to IIT. This activity may spill over to 2nd year.
- Training of personnel from IIT-KGP in operation of the facility will be carried out on BARC facility.
- Procurement of materials for welding and supplying same to IIT-KGP as when need

IInd Year:

- Assembly of all the subsystems at IIT-KGP and Commissioning of the facility by BARC engineers.
- Procurement of the dummy product samples from the users along with welding fixtures.
- Operation trials at rated specifications.
- Training of IIT-KGP researchers in the system

IIIrd Year:

- Participating in welding of samples for characterization as per the metal systems defined in section 3.
- Participation in establishing welding procedures for the end product through welding of dummy samples.
- Participating in Diagnostic Experiments and Development of soft computing models on weldability prediction.

8. ROLE AND RESPONSIBILITIES OF IIT-KGP

- IIT-KGP, will be responsible for providing all infrastructural facilities and manpower needed for the installation and running of the EB facility. It will be responsible for carrying out welding trials, weld characterisation and evolving a database. It will provide leadership in developing the predictive codes and diagnostic techniques. It will also take leadership in HR development in EB technology.

Ist Year:

- Preparation of the Technical project report specified in Section-6
- Literature survey and creation of data bank using available published works.
- Development of computer codes on weld dynamics
- Procurement of Welder sub systems, components and consumables for Electron Beam Welding Facility as per the specifications mentioned in the Project report.
- Familiarization / training of IIT-KGP personnel in the operations of an EB welding system at BARC.
- Participating in the testing of sub systems ready at vendor's site.

IInd Year:

- Procurement of remaining subsystems for EB Welding Facility, assembly and commissioning.
- Conducting weldability studies at IIT-KGP on metal systems mentioned in section 3
- Study on effect of process parameters on metallurgical and mechanical properties.
- Conducting weldability studies – preparing welded samples for metallurgical characterisation (using SEM, image analyzer, optical microscopy) and determination of mechanical properties

(strength, fracture toughness, fatigue) on similar and dissimilar materials by varying i) EB power, ii) Travel Speed, iii) Type of material and iv) Thickness of material.

IIIrd Year:

- Continuation of generating data on weldability studies
- Preparing weldability charts / nomograms.
- Developing of soft-computing models on weldability predictions.

In addition, short term courses on EB welding and related technology will be incorporated in to the yearly work schedule.

9. IMPLEMENTATION, PROGRESS REVIEW AND MONITORING

9.1 Project Implementation Committee (PIC)

- A Project implementation committee (PIC) consisting of Members as follows shall be responsible for all the activities of the project. The PIC shall coordinate activities such as the installation of the Electron Beam Welder and training of the IIT-KGP personnel. It would also provide technical inputs pertaining to the weld studies and the development of soft-predictive model. The PIC will be responsible for reviewing and expediting the technical progress of the project. The PIC will also assess all aspects of the proposal to be covered under an addendum to the MoU, Mid-course corrections, defining terms and conditions of release of payment, review of additional manpower requirement and make its recommendation to the Project Review Committee (PRC).

PIC from DAE	PIC from IIT-KGP Team
Dr. A. V. Bapat, Coordinator	Prof. G. L. Datta, Principal Investigator
Shri Martin Mascarenahas, Co Coordinator	Prof. I. Manna, Principal Co Investigator
Dr. J. Choudhury, Member	Prof. D K Pratihar, Member
Dr., G. K. Dey, Member	Prof. (Ms) J Datta Majumder, Member
Dr. A. K. Das, Member	Prof. Suman Chakravarty, Member
Dr. G. Gouthaman, Member	Prof. G. G. Roy, Member
Dr. J. Krishnan, Member	Prof. S. Roy, Member
Dr. Trilok Singh, Member	Prof. S. B. Singh, Member
Dr P.P.Chandrachoodan, BRNS, DAE	Prof. K. Biswas

The individual/group responsibilities of the investigators from IIT Kharagpur and BARC are listed in **Annexure – VI.**

9.2 Project Review Committee (PRC)

- Project shall be reviewed by a Project Review Committee (PRC) to see that the activities of the Project are well directed towards the objectives. The Project Review Committee shall consist of the following Members:

S.No.	PRC Members
1	Director, Beam Technology Development Group, BARC-Chairman
2	Director, IIT Kharagpur-Co-Chairman
3	Scientific Secretary, BRNS, DAE-Member
4	Chairman ATC, BRNS-Member
5	Head, Laser and plasma Technology Division-Member
6	Head, Dept. of Metallurgical and Materials Engg. IIT-KGP -Member
7	Head, Dept. of Mechanical Engg. IIT-KGP - Member
8	Project PI from IIT, KGP and Project Coordinator from DAE-Member

- The project funds will be released on a yearly basis on approval by the PRC. The PRC shall monitor the progress of the project every six months (preferably, June and December), and suggest ways and means for speedy implementation of the project. After the December review, it will recommend to BRNS for release of grants for the next financial year. It will also review the payment terms, and recommend requirement of additional funds to BRNS. PRC will also review the addenda to the MoU along with the report of the PIC, and will recommend the funds to be disbursed by BRNS and/or action to be taken by IIT-KGP. Towards the concluding phase of the third year, the PRC shall also constitute a **User Committee** (consisting of representatives of IIT-KGP, BARC and other DAE user groups) in place of the PIC. The PRC assisted by the User Committee shall be responsible for utilization of this facility setup under this MoU for the remaining period of the MoU and its extended periods.

10. RESOURCE REQUIREMENT, FINANCIAL TERMS AND MODE OF PAYMENT

The funds of 90 lakhs required for the design, development and procurement of the Electron Beam Welding Machine will be provided by BARC. The scope of this Purchase Order shall include spares necessary for routine maintenance of this machine for the period of this MoU. Tendering, vendor development and placement of the purchase orders will be handled by BARC with knowledge of IIT-KGP. Erection, commissioning and performance testing of the machine will be jointly handled by BARC and IIT, KGP. The ownership of the Electron Beam Welding machine shall remain with BARC for the MoU period and all its subsequent extensions. IIT-KGP will utilize the machine for R&D and manpower training activities.

The other financial components necessary to execute the project are indicated in the **Annexure - VII.** These funds will be released by BRNS. The terms and conditions of BRNS will apply.

Staff

For carrying out the research activity it is estimated that two SRF would have to be employed. Competent staff would be employed by IIT-KGP to run the system. Existing technical staff would be employed on a part time basis for various activities like welding preparation, sampling preparation for metallographic study and operation and maintenance of the equipment. The staff salary required has been estimated accordingly.

Travel

The project requires close interaction between IIT-KGP and BARC. Regular trips by the IIT-KGP faculty and Project staff will be essential for training / data verification and validation of soft-computing model for this. The travel funds required have been accordingly estimated. The travel expenditure of DAE personnel, for the integration, testing, commissioning and training of IIT-KGP personnel will be borne by the respective units of DAE.

Technical Assistance and Consumables

Expenses towards maintenance of the EB welder and miscellaneous hardware required are included under the head Technical Assistance and Consumables. Various ferrous (high alloy) and non-ferrous materials including filler metals for carrying out the weldability study will be procured under this head. Diffusion Pump oil, RP oil, electronic components, switchgear components, meters, filament material etc which are required to maintain the EB welder in operating condition will be procured under this head.

Contingencies:

Charges for fabrication, preparation and testing / characterization of samples are included under this head. Other incidental expenditure as allowed by the BRNS terms and conditions will be met from the contingency funds.

11. NO LIABILITY CLAUSE

BARC shall not be responsible for any loss or damage whatsoever, resulting due to implementation of the technology at the premises of the IIT-KGP.

12. CONFIDENTIALITY CLAUSE

IIT-KGP undertakes with BARC and BRNS not to transfer for any consideration to be received by it, the know-how/data obtained from BARC and BRNS through this MoU, to any other party in any manner whatsoever without the prior written approval of BRNS whether within and beyond the period of this MoU. IIT-KGP shall take all necessary measures to ensure that the knowledge/data obtained under this MoU is not passed on or disclosed.

13. PUBLICATIONS

Prior publications will be avoided where a patent or patents may possibly be taken. Publications, if any, of the know-how jointly developed by the two parties shall be in the names of the investigators from both parties. Research work carried out by either group separately during the course of the project may be published separately in open technical literature, subject to the above constraints. Any part of the work that has been carried out jointly by the two parties will be suitably acknowledged.

14. PATENTS & PATENT INFRINGEMENT

If the know-how developed as a result of the joint development programme leads to a patent or patents being taken, the parties hereto shall mutually agree whether or not to apply for a patent/patents and if so in which countries. Patents taken, if any, shall be in the joint names of the two parties. The cost of taking out a patent / patents shall be shared by the two parties, in the proportion to be mutually decided by BARC and IIT-KGP.

In the event of any claim or action being brought against either party to this MoU alleging infringement of a patent of a third party, the parties hereto shall mutually decide whether to defend the claim or not. The cost of defence against any such claim or action shall be born by the two parties hereto, in the proportion mutually decided by BARC and IIT-KGP.

It is understood that BARC and IIT-KGP will jointly own the IPR for the soft-computing model developed under the BRNS component. This means that either party has free use of the soft computing models for any technical work of its own for academic and industrial research, publications, projects, and consultative work. However, the software, even in an additionally developed form, cannot be fully or partly either given or sold to a third party for a period of five years after the completion of the project except with the written permission of both BARC and IIT-KGP. It will be within the rights of both the organisations to claim equal part of the proceeds of any such transactions during the said period.

Regarding IPR Theft

In case any third party is found to be illegally using the process code developed under MoU project, IIT-KGP and BARC may take legal recourse either jointly or separately (with mutual consultations).

15. INSURANCE

The collaborating parties shall affect insurance for their own personnel and property. Such insurance by one party shall include a waiver as to any insurer's action against the other.

16. MoU AND ITS AMENDMENTS

This MoU shall be the sole repository of the terms and conditions agreed to among the parties and no amendment thereof shall take effect or be binding on the parties unless such amendment is authorised by them and is recorded in writing and signed by the duly authorised representatives of all the three parties.

17. ASSIGNMENT

This MoU shall not be assignable by any of the three parties without the prior written consent of the others except that this agreement shall be automatically binding upon and inure to the benefit of any successor of any of the parties.

18.TERMINATION

In case it is found by the two parties that the desired objectives cannot be achieved due to any reason(s) whatsoever, this MoU will be treated as terminated by a mutually agreed procedure without any liability on any of the three parties.

19.FORCE MAJEURE

Neither party shall be held responsible for non-fulfilment of their respective obligation under this agreement due to the exigency of one or more of the force majeure events such as but not limited to Acts of God, War, Flood, Earthquakes, Strike(s), Lockout(s), Epidemics, Riots, Civil commotion etc provided on occurrence and cessation of such events, the party affected by these shall give a notice in writing to the other party within one month of such occurrence and cessation. If the majeure conditions continue beyond six months, the parties shall then mutually decide about the future course of action.

20.ARBITRATION

If any dispute arises among the parties to this MoU regarding implementation of the terms of the MoU or any other matter incidental to or connected with the subject matter of the MoU, such dispute shall be resolved as far as possible amicably by mutual consultations, failing which, a reference may be made by the parties to the Secretary, Department of Atomic Energy, Government of India as a measure of last resort. The decision shall bind the parties finally and conclusively and the parties will share equally the cost of arbitration as intimated by the arbitrator.

This MoU will be effective from the date when all the parties to the MoU have signed it. In witness whereof, the parties hereto have executed this MoU through their authorised representatives.

FOR AND ON BEHALF OF
BHABHA ATOMIC RESEARCH CENTRE

Signature Srikumar Banerjee
Name SRIKUMAR BANERJEE
Designation DIRECTOR
Place Kharagpur
Date 16 NOV 2006

Witness:
1. (A.V. BAPAT) BARC
2.

FOR AND ON BEHALF OF
INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Signature 16.11.06
Name
Designation
Place
Date

प्रोफेसर शिशिर कुमार दुबे
Prof. Shishir Kumar Dube
निदेशक
Director
भारतीय प्रौद्योगिकी संस्थान
Indian Institute of Technology
खड़गपुर ७२१ ३०२, भारत
Kharagpur - 721 302, India

Witness:
1. C.P. Chakravarthy 16/11/06
2. (G.L. Datta)

FOR AND ON BEHALF OF
BOARD OF RESEARCH IN NUCLEAR SCIENCES, DEPARTMENT OF ATOMIC ENERGY

Signature
Name B.K. BANDARI
Designation ASSOCIATE DIRECTOR
Place
Date Nov 16, 2006

Witness: (A.V. BAPAT), BARC
1.
2.

Annexure – I

S. No	Type of Equipment	Special Features	Users
1	Melting 6 kW, 15 kV	Melting of refractory and reactive metals Buttons, fingers and rings. 0.5 kg. Of Ta in one charge. Beam Spot diameter– 12 mm	NML, Jamshedpur; Met. Divn. BARC; AFD, BARC; NAL, Bangalore.
2.	Melting 7.5 kW, 15 kV	More compact power supply than above Bar feeding arrangement incorporated, manufactured at IBP under technology transfer program.	NPL, New Delhi
3.	Melting 15 kW, 15 kV	600 mm diameter Ta rings of 25 mm cross-section could be produced. Gun chamber separately evacuated. Beam diameter – 18 mm	NFC, Hyderabad
4.	Melting 15 kW, 15 kV	Smaller work chamber than above. Bar feed and vibratory feed with retractable crucible for ingot casting, manufactured at IBP under technology transfer program	Met. Divn. BARC; IGCAR Kalpakkam
5.	Welding 6kW, 30 kV	High vacuum welder. No separate gun pumping. Welding of reactive and refractory metals. Beam diameter – 3 mm	Within BARC for Weld development
6.	Welding 10 kW, 40 kV	Welding at 10-2 mbar. Weld head rotated over the joint for tube-to-tube sheet weld. Beam diameter – 2mm	Within BARC for Weld development
7.	Welding 6 kW, 150 kV	Welding at 10-2 mbar. 1m x1m x1.5m work chamber. Power supply modified in 1987. New worktable installed in 1995.	Within BARC for Weld development/internal use
8.	Evaporation 10 kW, 40 kV	Beam bent to 45 degree. Evaporation of various reactive metals. Tungsten evaporation rate at 5 kW – 15 mg/sec/cm2	Within BARC for evaporation studies
9.	Melting 80 kW, 30 kV	Melting of refractory metals. Ingot size up to 40 mm diameter	Within BARC, Met. Divn.
10.	Evaporation 30 kW, 30 kV	Beam bent to 45 degrees. Operated up to 20 kW.	Within BARC for evaporation studies
11	Welding 6 kW, 150 kV	Work chamber 1.5 m x 1.5 m x 2 m operating at high vacuum of 10^{-5} mbar.	MTPF, Ambernath for coronet welding
12	Evaporation 10 kW, 10 kV	Beam bent by 270 degrees. Gun mounted below copper crucible. Operated up to 5 kW.	Within BARC. Development of new coatings
13	Evaporation 200 kW, 60 kV	Beam bent by 270 degrees. Strip beam 200 mm x 5 mm.	Within BARC for evaporation studies
14	Welding 4 kW, 120 kV	Refurbished 150 kV E8 welder. Welding carried out at 10^{-5} mbar	M/s Sidhhi Engg Co. for industrial utilization
15	Welding 80 kV, 24 kW	Work Chamber 2 m x 2 m x 3 m. Welding carried out at 10^{-5} mbar	Within BARC, CDM Divn.

Annexure – II: Welding Jobs

Sl. No.	Name of Job	Material Welded	Users
1.	Electrode Modules	SS - Porous Nickel	Heavy Water Board
2.	Toroidal Detector Assembly	0.1mm SS	
3.	Rotating Anode	Cu-SS	
4.	Linear Accelerator Cavity	Cu-SS	
5.	Rotor	Maraging steel	
6.	Coronet	Maraging steel	Ministry of Defence

Annexure – III a
Weldment Characterisation: Metallurgical & Mechanical

Sl.	Characteristics to be studied	Tools to be used
1.	Macrostructure	Eye, Optical
2.	Microstructure	OM, SEM, TEM, XRD
3.	Micro composition	EDS, WDS, SIMS
4.	Segregation	EPMA
5.	Mechanical Property	Hardness, Bending Test, Retained Stress
6.	Physical	Contour, shape
7.	Thermal	Dilatometry
8.	Texture	
9.	Interface and HAZ	
10.	Depth profile	

Annexure IIIb
Microstructural Characterization of Fusion Welding by Electron Beam

Fusion welding in butt joint configuration involves partial melting of two contacting surfaces followed by solidification by self-quenching. Integrity and strength of the joint primarily depends upon the thermal history, thermo-physical properties (of the weldments), and heat/mass/momentum transfer within the melt pool and hence the resultant microstructure and composition profile evolved across the joint. While mathematical modeling by numerical simulation can predict the thermal history including temperature profile, heating/cooling rate, thermal gradient and solidification velocity, microstructural characterization including compositional microanalysis is essential to establish the mechanism of joining, degree of bonding or strength, and causes of defects/failures. Furthermore, microstructural characterization provides suitable validation of the numerical predictions concerning weld pool geometry, contour, crystallite size, compositional profile and mechanical properties. In brief, microstructural characterization is absolutely essential to determine the optimum conditions and micro-mechanism for successful welding.

In the proposed work concerning electron beam welding of (a) Zircaloy to Zircaloy, (b) Maraging steel to Maraging steel and (c) stainless steel to Zircaloy the major process parameters identified are:

- Linear traverse speed of the work piece
- Power density (in terms of applied voltage or current)
- Location of beam focus w.r.t. the sample surface
- Welding pressure in the chamber

- Plate thickness or pool profile (deep or partial penetration welding)
In addition, the influence of (a) filler material and (b) oscillation or deflection will also be considered.

For a complete microstructural characterization, the overall scheme of investigation will include (but be not limited to) studies on:

(a) **Solidification macrostructure** by visual inspection, non-destructive testing (NDT) and low magnification microscopy to determine the size, distribution and width of chilled/columnar grains and defects (porosity, bulging, shrinkage, cracks, etc.), if any.

(b) **Microstructure** by optical (OM), scanning (SEM) and transmission electron microscopy (TEM) to determine the shape, size, distribution and volume fraction of the phases evolved. In addition, X-ray diffraction or selected area diffraction (SAD) with TEM will be employed to identify the phases formed in the weld pool.

(c) **Compositional microanalysis** will be carried out by energy (EDS) or wavelength dispersive spectroscopy (WDS) in selected regions of the microstructure to determine composition of a given phase, spot, area or line to supplement microstructural investigated by SEM and TEM.

(d) **Segregation profile** will be determined for elements of interest (C, S, N, Al, etc.) along inter-dendritic spaces or between directional grains. Segregation is mostly undesirable as it leads to evolution of undesirable phases and premature mechanical/electro-chemical failure.

(e) **Thermal properties** like coefficient of thermal expansion, transformation temperature and enthalpy/heat changes will be evaluated by dilatometer, differential thermal analysis (DTA) and differential scanning calorimeter (DSC), respectively. These parameters are essential for design and life prediction of components and correlation between microstructure and mechanical properties.

(f) **Mechanical properties** like microhardness profile, tensile/bending strength, tensile/bending elongation, and fatigue/fracture strength will be evaluated in selected number of samples in appropriate geometry/configuration. Mechanical properties will be the ultimate criterion for assessing acceptability of the welding routines.

In addition to the above, attempts will be made to study the (a) texture (preferred orientation) evolution, (b) residual stress pattern/magnitude, and (c) physical shape/contour of the weld. Furthermore, microstructural investigation at appropriate sections (longitudinal and transverse) and depths (from the top surface) will allow reconstruction and development of microstructural description of the welded joint in three-dimension. These data will provide valuable input to results of numerical simulation and modeling.

It may be noted that microstructural studies include specific investigation related to heat affected zone (HAZ) and solid-liquid interfacial zone as well.

In general, the overall aim of the microstructural characterization exercise, as described above, will be to establish and appropriate microstructure-property-process parameter correlation.

Additional Benefits and Future Plan:

1. Man power training for doctoral, masters and bachelors level students and their theses including engineers/scientists from BARC.

2. Short term courses for teachers, engineers and scientists from institutions/organizations other than IIT-KGP and BARC.

3. Supplementary activities and projects on e-beam assisted cladding and surface engineering of components/materials of interest to BARC.

4. Incorporation of on-line and in-situ diagnostic and monitoring tools like infra red temperature detectors, thermo couples, high speed camera and sensors to generate rare and valuable data on thermal and liquid pool characteristics for the materials of interest during welding (through separate projects).

5. Creation of an extensive database and handbook for welding of difficult to weld metals and alloys and interest to BARC/DAE. Future activities (beyond the current MoU) may extend the scope of work to metals and alloys not included in the present study.

Time schedule of activities giving milestones:

	ACTIVITIES	1ST YEAR				2ND YEAR				3RD YEAR			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.	SETTING UP OF E-BEAM WELDING FACILITY												
2.	PRELIMINARY TRIALS WITH SMALL COUPONS AT BARC												
3.	VISUAL AND MICROSTRUCTURAL CHARACTERIZATION BY OM, SEM AND XRD												
4.	MICROSTRUCTURAL CHARACTERIZATION BY TEM AND COMPOSITIONAL PROFILING												
5.	ASSESSMENT/TESTING OF MECHANICAL, PHYSICAL AND THERMAL PROPERTIES												
6.	STUDIES ON INTERFACIAL STRENGTH AND OTHER PROPERTIES												
7.	STRUCTURE-PROPERTY-PARAMETER CORRELATION AND VALIDATION OF SIMULATION AND MODELING												
8.	FINAL DOCUMENTATION												

Annexure - IV
Diagnostics and process validation:

Temperature profiles on the surface of the melt pool will be traced using a suitable CMOS sensor. Temperature profiles will help to capture the initiation of any keyhole during the welding process. The measured temperature profiles will be very useful data for metallurgical analysis. It will also be required for validation of the computer model of the melt pool.
A high speed CMOS camera with frame grabber card mounted in a PC will be used to capture video images. The video images will be converted to temperature profiles using suitable software.

Annexure V
On-line Control of the Process: Using Soft Computing Tools

To automate a process, its input-output relationships are to be known beforehand. Knowing the inputs, the output(s) of a process can be determined by using some statistical methods, such as regression analysis, response surface methodology, and others. On the other hand, it could be difficult to select the proper combination of different input parameters, to obtain a set of desired outputs, particularly by using the statistical methods. It is so, because matrix inversion may not always be possible in such cases. It is interesting to note that soft computing (i.e., genetic algorithms, fuzzy logic technique, neural networks and their different combinations) may provide a feasible solution (within a reasonable accuracy) to both the forward as well as backward mappings as mentioned above.
To provide an on-line control of the Electron Beam Welding process, the following steps are to be followed.

- Identification of input and output parameters of the process.
- Measurement of the outputs for a set of inputs using the measuring devices/sensors.
- Implementation of both the forward as well as reverse mappings using soft computing.
- Determination of the error in prediction and the feedback to be provided.
- Implementation of the feedback to be given, for the said purpose.
- Performance testing.

Annexure – VI
Simulation of Weld Pool

The main objective of the Computational Fluid Dynamics (CFD) studies to be executed for this project is to mathematically model and computationally simulate the transport phenomena (heat, mass and momentum transfer) involved in electron beam welding of metals, and then link it to predict the microstructure formation in the weld zone. The knowledge developed would be useful for improving existing processes and developing newer processes and materials with desired properties. As an outcome of the numerical simulation, the following are expected to be achieved:
- Prediction of thermal profile
- Prediction of compositional profile
- Prediction of microstructural features
- Extend the analysis to more complex binary metallic systems
- Experimental validation of the model developed

Annexure - VII

SHARING OF RESPONSIBILITIES ON BEHALF OF IIT KHARAGPUR

	Activities	Investigators
1	Indenting, installation and commissioning of EBW machine, procurement of consumables	Prof. G.L. Datta
2	H.R.D	Prof. G.L. Datta
3	Experimentation and determination of mechanical properties of weldment	Prof. G.L. Datta, Prof. K. Biswas and Prof. S. B. Singh
4	Diagnostics and process validation	Prof. S. Roy
5	Metallurgical characterisation of weldments	Prof. I. Manna and Prof. J. Datta Majumdar
6	Modeling of solidification phenomena	Prof. Suman Chakraborty, Prof. G. G. Roy
7	Modeling of weld characteristics using soft computing tools	Prof. D.K. Pratihar
8	Overall Coordination	Prof. G.L. Datta

SHARING OF RESPONSIBILITIES ON BEHALF OF BARC

	Activities	Investigators
1	Indenting, installation and commissioning of EBW machine, procurement of consumables	A. V. Bapat/Shri M. Mascarenahas
2	H.R.D	A. V. Bapat, J. Choudhury, J. Krishnan
3	Experimentation and determination of mechanical properties of weldment	A. V. Bapat/Shri M. Mascarenahas
4	Diagnostics and process validation	A. K. Das, A. V. Bapat
5	Metallurgical characterisation of weldments	G. K. Dey
6	Modeling and Simulation	A. K. Das, A. V. Bapat
7	User Interface	G. Gouthaman, J. Krishnan, J. Choudhury
8	Overall Coordination	A. V. Bapat

Annexure -VII

Budget Amounts in Rupees (lakhs):

Particulars	I Year	II Year	III Year	Total
Staff Salaries:				
SRF(2):	3.60	3.60	4.00	11.20
RA:				
Temp. Staff:				
Technical Assistance: &Consumables	2.30	5.10	5.10	12.50
Travel PI:	1.80	1.80	3.00	6.60
PC/DC:	0.60	0.60	0.60	1.80
Contingencies:	3.50	5.50	1.50	10.50
Overheads:	2.00	0.50	3.50	6.00
Total	**13.80**	**17.10**	**17.70**	**48.60**