Form B: IGEM-HERC Full Proposal Cover Sheet

PROPOSAL NUMBER:	TOTAL AMOUNT REQUESTED: $157,500
Proposal Track: Proof of Concept	

TITLE OF PROPOSED PROJECT	Joining of Non-Oxide Ceramic Components Used in Extreme Environments
SPECIFIC PROJECT FOCUS	ENERGY, Nuclear Energy, Energy-Environment Interaction
PROJECT START DATE: 07/01/2025	PROJECT END DATE: 06/30/2016
NAME OF INSTITUTION	University of Idaho
DEPARTMENT	Nuclear Engineering and Industrial Management
ADDRESS	1776 Science Center Drive, Idaho Falls, ID 83402
Email: ksraja@uidaho.edu	Phone: 208-757-5406

	Name	Title	Signature
Principal Investigator	Krishnan S Raja	Professor	Krishan S Raja
Co-PI	Indrajit Charit	Professor and Chair	Indrajit Charit

Name of Partnering Company	NuCube Energy, Inc.
Name of Company Representative	Mitchell K Meyer Mitch Meyer, Ph.D., Director, Nuclear Fuels and Materials

Authorized Organizational Representative	Name: Sarah S Martonick	Signature: Sarah S Martonick

1. Name of primary Idaho public institution: University of Idaho

2. Project title: Joining of Non-Oxide Ceramic Components Used in Extreme Environments

3. Name and Institution of Principal Investigator(s) and Key Personnel: Krishnan S. Raja (PI) and Indrajit Charit (Co-PI), Nuclear Engineering, University of Idaho, Idaho Falls, ID 83402.

4. Total amount requested: $157,500

5. Significance of project and project objectives

5. 1 Summary of the Project: Non-oxide ceramic materials such as silicon carbide (SiC), zirconium boride (ZrB_2), and hafnium boride (HfB_2) are used in extreme environments due to their high melting point (> 2700 °C), excellent strength at high temperatures, resistance to thermal shock and good chemical stability. SiC-based materials are currently considered for use as fuel cladding tubes, control rods, and core structural materials in advanced nuclear reactors [1]. SiC is a promising material for aerospace and power generation applications such as rocket nozzles, gas turbines, and engine components [2]. ZrB_2 and HfB_2 are used in leading edges and nose cones of hypersonic vehicles and candidate electrode materials of coal-fired magneto hydrodynamic direct power extraction systems [3]. Developing a robust and cost-effective joining technology is required to implement more complex ceramic components that enable systems' safe and efficient operation in extreme environments. Developing ceramic material joining processes to make complex shapes has been ongoing for several decades without commercial success. Short-term implementation of these components and future uses are severely constrained by the difficulty in forming and/or machining components other than simple plates, tubes, and bars and ensuring hermetic sealing, even on simple shapes. The proposed project addresses this limitation. The proposed research will use electric-field-assisted processes to directly join ceramic materials (no interlayer). The joining process will be further enhanced through modification of the surfaces (one end is metal/metalloid terminated (Zr, Hf or Si), and the other end to be joined is non-metal (boron or carbon) terminated) to promote Zr-B or Si-C reactive bonding. Achieving a direct bonding without any filler material (braze) will be *game-changing* because the joint is not the weakest link anymore. The proof-of-concept of this work will attract federal and private funding because this project addresses a critical constraint experienced in extreme environments.

5.2 Background: SiC exists in different polymorphs. The cubic lattice structure (β-SiC) is widely used in structural applications, while the hexagonal crystal structure (α-SiC, 4H or 6H) is used in semiconductor applications. The predominantly covalent-bonded SiC shows directional bonding

[1] Huaxin Li, Takaaki Koyanagi, Caen Ang, Yutai Katoh, Journal of the European Ceramic Society 41 (2021) 3072–3081

[2] Long Zhou, Chun Li , Xiaoqing Si, Chenghao Zhang, Bo Yang, Junlei Qi, Jian Cao, Journal of the European Ceramic Society 43 (2023) 2713–2717

[3] Sitler S. J., Hill C. D., Raja, K. S. & Charit, I. Transition Metal Diborides as Electrode Material for MHD Direct Power Extraction: High Temperature Oxidation of ZrB_2-HfB_2 Solid Solution with LaB_6 Addition. Metall. Mater Trans E. 3E, 90-99 (2016)

and limited diffusivity in specific crystallographic directions, which requires very high temperature (>1800 °C) and high pressure (> 10 MPa), making direct SiC/SiC bonding complex and cost-prohibitive [4]. To overcome the constraints of direct bonding, a low-melting interlayer is often used as a filler material (braze) [5]. However, this weak link is prone to mechanical failure as residual stresses develop because of mismatches in thermal expansion and radiation swelling between the joint and substrate. Degradation and failure may also occur because of the formation of brittle intermediate phases. A sound joint can be obtained by considering and controlling these detrimental factors.

Zirconium and hafnium diborides have a melting temperature of ~ 3245°C, high thermal conductivity (60 W/(m·K) and high thermal shock resistance [6]. ZrB_2 and HfB_2 also show high electrical conductivity owing to the metallic bonding in the Zr/Hf planes and metal-like electron configuration with a finite electron density of states at the Fermi level [7]. SiC of 10–30 vol% is added to ZrB_2 to inhibit oxidation to temperatures above 1600°C. SiC additions also improve the strength of ZrB_2, which can be as high as 1 GPa at room temperature. Joining of ZrB_2 or ZrB_2-SiC composites is typically performed using filler materials such as elemental metals, metal alloys, or metallic glass oxides [8]. The filler's compositions are significantly different from the substrates and produce large reaction zones and inhomogeneous microstructures across the joint, making the joint the weakest link by substantially lowering the design strength. The joints were also processed using low-temperature liquid forming fillers, which limit the joined part's application temperature to the filler's melting temperature, <1400°C. Direct fusion welding of the ZrB_2/SiC resulted in significant cracking and other defects, such as porosity and lack of fusion [9].

For manufacturing complex components for use in extreme environments via the joining process, the ceramic joint must exhibit several desired attributes such as: (1) the mechanical, electrical, and thermal properties of the joined ceramics should be the same as the parent material at room and elevated temperature; (2) the joining process should not alter the physical properties or geometry and shape of the parts after joining; (3) the microstructure at the joint should be similar to the parent microstructure and have almost the exact composition of the parent material as to ensure continuity of properties across the joint; and (4) the joining method should be a rapid, reproducible, and scalable process [6].

<u>5.3 Proposed Innovative Approach</u>: This project aims to develop a direct ceramic-to-ceramic joining method without using a filler material or an interlayer. The direct joining will be achieved

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[4] M. Herrmann, P. Meisel, W. Lippmann, A. Hurtado, Nuclear Engineering and Design Volume 306, September 2016, Pages 170-176

[5] Chuang-Tian Zhan, et al., Journal of the European Ceramic Society 43 (2023) 3070–3076

[6] W. R. Pinc, M. Di Prima, L.S. Walker, Z. N. Wing, and E. L. Corral, J. Am. Ceram. Soc., 94 [11] 3825–3832 (2011)

[7] Steven J. Sitler, Krishnan S. Raja, Indrajit Charit, Hot corrosion behavior of ZrB2-HfB2 solid solutions in KCl and K_2SO_4 at 1500 °C, Ceramics International 43 (2017) 17071–17085

[8] S. Bajpai, et al., Chemical Engineering Journal 495 (2024) 153387

[9] Jecee D. Jarman, et al., Journal of the European Ceramic Society 42 (2022) 5195–5207

by electric field-assisted heating of the interface and diffusion of atoms under compressive stress. Fig. 1 schematically illustrates the electric-field-assisted direct joining (EFAJ) process [1]. In this arrangement, an alumina die will be used instead of a graphite die to hold the samples in place so that all the current flows only across the joint interface for effective joule heating and not through the die set. Furthermore, the mating surfaces will be controlled so that the surface roughness is very low to maximize the contact area and minimize the asperity contact. The real innovation of the proposed method is the modification of the surfaces to be joined. We hypothesize that the joint quality will improve if carbon-terminated and silicon-terminated surfaces are combined to achieve atomic bonding in SiC-SiC joints. Similarly, mating the boron-terminated surface with the Zr-terminated surface will help achieve the highest bond strength. Fig. 2 schematically illustrates the approach. Applying an electric field and pressure will fuse the surface-modified mating parts together, forming a high-strength joint.

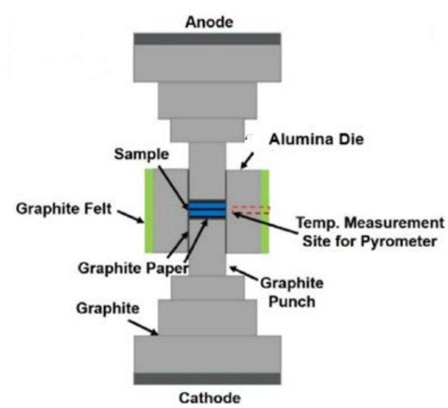

Fig. 1 Schematic illustration of electric field-assisted direct joining of SiC -SiC [1].

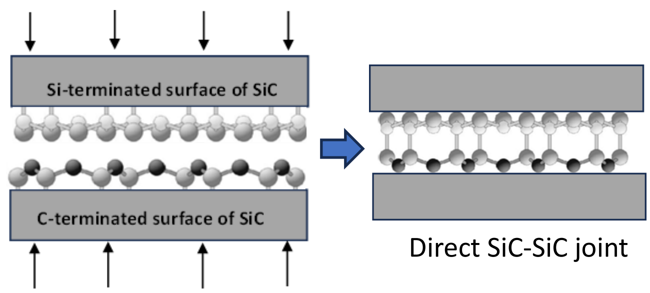

Fig. 2 Schematic illustration of direct joining of Si-terminated and C-terminated surfaces.

<u>5.4 Objectives of the Project:</u>

The objectives of this proof-of-concept project are to:

- Prepare metal-terminated (such as Zr, Hf, or Si) and non-metal terminated surface of mating sections of ZrB_2, HfB_2, and SiC test coupons using a scalable process;
- Establish process parameters for the electric field-assisted direct joining method to join the surface-modified ends of different ceramic materials;
- Evaluate the microstructural and mechanical properties of the joints and fine-tune the process parameters so that the joints are not the weakest links and
- Translate the proof-of-concept to join complicated configurations for manufacturing components used in extreme conditions.

6. Specific Project Plan and Timeline

<u>Task 1 Surface Modification of Samples</u>: <u>Background</u>: Surface modification of mating surfaces of the ceramic materials SiC and ZrB_2 involves rendering the surfaces terminated with Si and C in the case of SiC and Zr and B in the case of ZrB_2. Single atomic-layered silicon, carbon, and boron structures are called silicene, graphene, and borophene. These single-layered structures show interesting properties and are used in different applications. Silicene, the two-dimensional, one-atom-thick single-layer building sheet of silicon, is the silicon analog of graphene and exhibits many superior properties. The structure of silicene is schematically illustrated in Fig. 3. The

silicene film fabrication must be conducted in an ultrahigh vacuum (UHV) environment due to the sensitivity of Si upon oxidation. Owing to the clean environment and easy control of the deposition coverage with sub-monolayer precision, molecular beam epitaxy (MBE) is preferable to fabricating silicene sheets via epitaxial growth of silicon on solid substrates. Graphene, a single layer of sp^2-hybridized carbon atoms, is one of the most advanced two-dimensional materials. Epitaxial graphene growth on a SiC substrate using a thermal decomposition process (epitaxial graphene: EG) is industrially reasonably practical [10]. Borophene is an atomically thin boron sheet with interesting physical and mechanical properties [11]. Various borophene structures have been predicted, ranging from triangular to hexagonal arrangements of boron atoms with diverse configurations and numbers of atomic voids. Both chemical and physical vapor deposition (CVD and PVD) methods are employed to prepare borophene layers on different substrates. Mechanical and electrochemical exfoliation methods are used as top-down techniques to prepare the borophene layers. The PVD methods include molecular beam epitaxy at ultra-high vacuum conditions at 350 – 550 °C. The CVD method is based on the thermal decomposition of the boron precursors such as diborane (B_2H_6) or borazine ($B_3N_3H_6$) at < 560 °C and annealing the boron deposit in vacuum at temperatures > 850 °C. It is hypothesized that the surface modification of the mating surfaces with M-xene-type layers will promote better bonding at low temperatures and pressures.

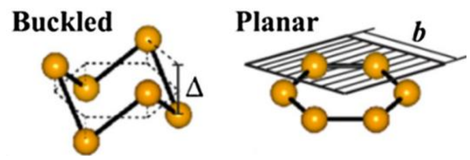

Fig. 3 Schematic of the silicene structure. Left panel: Side view; Right panel: planar

Approach: In this project, the β-SiC samples will be investigated in the form of 6 to 10 mm diameter and 10 - 20 mm long cylindrical pins and/or 10 mm diameter, 0.5 mm wall thickness tubes, depending on the availability. The ZrB_2 samples will be prepared by spark plasma sintering commercial ZrB_2 powder. 12 mm diameter, 10 - 15 mm thick cylindrical pellets will be sintered using a spark plasma sintering machine (Fuji Electronics, Japan, model: Dr. Sinter SPS-515 S). No sintering aid will be added. An Isocarb-85 graphite die with a 12-mm diameter will be used with 5 - 10 kN of applied force at 1700 °C for 600 s – 1200 s under a ~ 10^{-3} Torr vacuum [7].

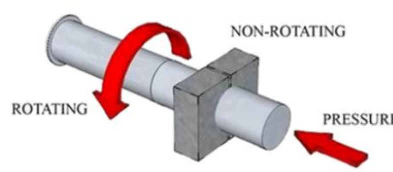

Fig. 4 Schematic illustration of preparation of mating surfaces for EFAJ.

The first step of surface modification of the mating surfaces is to prepare the mating surfaces. Perfectly matching surfaces for EFAJ will be prepared by controlled rubbing of the surfaces to be joined, as illustrated schematically in Fig. 4. This step will ensure that the mating surfaces have tightly matching surface profiles. These matching surfaces will be marked as a pair and taken for the surface modification step. One mating surface of the SiC sample will be modified to have a Si-termination, and the other will have a carbon-termination layer. The carbon-terminated surface of β-SiC will be obtained by thermal annealing at 1250 °C in a vacuum. During the annealing, silicon is oxidized to SiO and removed, leaving a clean C-terminated surface [12].

[10] K.S. Kim et al., Carbon 130 (2018) 792-798
[11] O. G. Yildiz, U. Aydemir, Materials Science & Engineering R 163 (2025) 100913
[12] P. Soukiassian, et al., Phys. Rev. Lett. 78 (1997) 907.

Another approach for producing monolayer epitaxial graphene (mono-EG) on the β-SiC substrates is by annealing them under an Ar atmosphere at 1325 °C for 20 min using a conventional furnace [10].

The silicon-terminated surface will be obtained by magnetron sputtering or room temperature deposition of silicon by arrayed DC microplasma onto the β-SiC surface [13]. Room temperature Si deposition onto a β-SiC surface followed by thermal annealing at 1000 °C – 1150 °C in high vacuum also results in a Si-terminated surface. A qualified vendor will perform the silicon deposition. The pairs of C-terminated and Si-terminated surfaces will be joined without any filler materials using the EFAJ process described in Task 2. The phase diagram of Si-C shown in Fig. 5 suggests that a eutectic mixture forms at 1413.8 °C [14]. The eutectic carbon concentrations in liquid and solid Si were respectively reported to be 42 ppmw and 3 ppmw [12]. We will explore the eutectic formation to obtain a porosity-free weld joint. The eutectic formed in the joint line will be rich in silicon initially. However, continuous heating will level the concentration gradient at high temperatures. The ZrB_2-ZrB_2 joining will be performed by creating Zr-terminated and B-terminated surfaces of ZrB_2. A physical vapor deposition process will coat a monolayer of zirconium and a monolayer of boron on the ZrB_2 surfaces to be joined. The crystal structure of ZrB_2 is of the AlB_2 type, consisting of an alternating stacking of graphite-like boron layers and hexagonal metal layers along the [0001] direction [15]. Treating the ZrB_2 samples in hydrofluoric acid for 1- 10 minutes, washing, drying, and vacuum annealing at 800 – 1000 °C for one hour resulted in a Zr-terminated surface [16]. This task will follow a similar procedure to obtain Zr-terminated ZrB2 mating surfaces. A second approach to get a Zr-terminated surface will be to sputter coat the mating surface of the ZrB_2 sample with zirconium by the magnetron sputtering method.

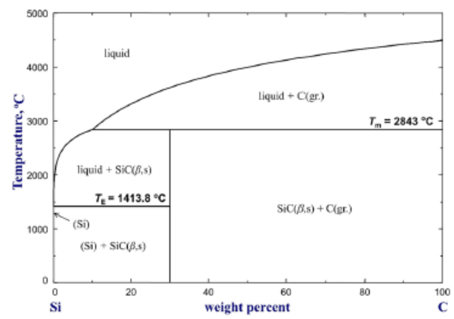

Fig. 5. Si-C binary phase diagram. An eutectic mixture of Si-42 ppm of C occurs at 1413.8 °C

Similarly, a two-pronged approach will be employed to obtain boron-terminated mating surfaces of the ZrB_2 samples. The first approach will employ magnetron sputter boron coating on the ZrB_2 sample, followed by vacuum annealing at > 850 °C for one h. The second approach will be based on the top-down technique involving ultrasound-assisted exfoliation. Ultrasound waves generated by a high-power ultrasonic transducer focused on the ZrB_2 samples will irradiate the sample and preferentially break the Zr-B bonding, exposing the boron-terminated surface. The specific surface terminations will be verified using Raman microscopy. It should be noted that metallic bonding is not Raman active. Raman spectroscopy will be a simple and reliable tool to evaluate the surface structures [10-12]. These surfaces will be joined under a vacuum using the

[13] Chester G. Wilson, Yogesh B. Gianchandani, 17th IEEE International Conference on Micro Electro Mechanical Systems. Maastricht MEMS 2004 Technical Digest, 2004, DOI: 10.1109/MEMS.2004.1290697
[14] Zhimin You, Zhouhua Jiang, In-Ho Jung, Journal of the European Ceramic Society 42 (2022) 4793–4809
[15] S.J. Sitler, K.S. Raja, I. Charit, Metal Rich Transition Metal Diborides as Electrocatalysts for Hydrogen Evolution Reactions in a Wide Range of pH, Journal of The Electrochemical Society, 2016, 163 (13) H1-H7
[16] Hirofumi Suto et al 2006 Jpn. J. Appl. Phys. 45 L497

FEAJ process. The process parameters will be optimized to obtain the desired mechanical properties.

<u>Deliverables in four months</u>: Modified surfaces of the mating surfaces of samples for further processing. The cylindrical and tubular sample surfaces of the β-SiC will be modified as Si-terminated and C-terminated for further processing. The mating surfaces of the ZrB_2 will be modified as Zr-terminated and B-terminated for further processing.

<u>Task 2 Electric Field-Assisted Direct Joining (EFAJ) of SiC</u>:

Table 1. SiC Joining Processes and Properties [17]			
Joining method	**Bonding layer**	**Processing conditions**	**Properties**
Solid state diffusion bonding	None or refractory metallic foils such as titanium and molybdenum	~2000°C, >~15 MPa ~1500°C, >~2 MPa, (~0.1 MPa)	Shear strength: 56-83 MPa @ 1500 °C
Metallic braze-based	Metallic fillers	~1000°C, low/no pressure	Bend strength: 150 – 250 MPa @ 1400 – 1600 °C.
Glass ceramics	Ca-Al-O, Si-Al-Mg-O, Y-Al-Si-O	~1500°C, no pressure	Shear strength: 40-69 MPa
SiC pre-ceramics precursors	SiC	<~1500°C, ~0.01 MPa	
Reaction sintering with Si-C and Ti-Si-C systems	Si-C and Ti-Si-C	≤~1500°C, no pressure	
Liquid-phase sintering	SiC powder and sintering additives	~1850°C, ~10 MPa	K_{IC} = 2.6-3.5 MPa√m, Flexural strength: 317 – 638 MPa
Selected area CVD/ CVI	SiC	<~1200°C, low pressure	Shear Strength 93 MPa, UTS 412-509 MPa
EFAJ using modified mating surfaces TThis project)	No external bonding layer	< 1200 °C, low pressure	Shear strength > 100 MPa

Table 1 summarizes the current practice of SiC-SiC joining processes and their mechanical properties [[17]. The proposed electric field-assisted joining of surface-modified mating surfaces will be performed without any filler material, the target shear strength will be > 100 MPa, and the joint will have a similar strength to the parent material.

[17] T. Koyanagi, et al., SiC/SiC Cladding Materials Properties Handbook, ORNL/SPR-2017/385

Approach: Initially, the electric-field assisted joining (EFAJ) experiments will be performed using the unmodified surfaces to estimate the process parameters. The first step of the joining trial is to obtain perfectly matching surfaces by rubbing the two surfaces to be joined, as schematically shown in Fig. 4. Matching surfaces will be prepared using the following pairs: SiC-SiC, ZrB_2-ZrB_2, and SiC-ZrB_2. After preparing the matching pairs, EFAJ experiments will be performed using a spark plasma sintering (SPS) machine, Dr. Sinter, SPS-515S machine (Fuji Electronic Industrial Co., Ltd., Japan) available with the Center for Advanced Energy Studies (CAES, Idaho Falls). The SPS tooling will be kept under a vacuum of at least 10^{-3} Torr for the entirety of the SPS operation. The applied pressure will vary from 5 – 60 MPa. The samples will be heated to different temperatures in the 1400 – 2100 °C range. A heating rate of 100 °C/min will be applied during SPS. The processing time will vary from 5 – 15 minutes. The process parameters will be optimized based on microstructural and mechanical properties characterization, as discussed in Tasks 3 and 4. The optimized parameters will be used for the EFAJ runs of the surface-modified samples. The samples obtained from Task 1 will be joined by the EFAJ process using the spark plasma sintering machine and the optimized parameters of the unmodified samples.

Deliverables: 'Welded' joints of unmodified and surface-modified samples of different materials, such as SiC-SiC, ZrB2-ZrB2, and SiC-ZrB2, will be prepared using the EFAJ process for further characterization in Tasks 3 and 4. This task will continue for up to nine months.

Task 3 Microstructural Characterization of the Joints: Small portions will be sectioned from the SiC-SiC, ZrB_2-ZrB_2, and SiC-ZrB_2 joints prepared in Tasks 1 and 2. The cross-sectional microstructures of the joints will be analyzed using optical, FESEM, and TEM techniques. Confocal Raman microscopy will be performed to understand the interfaces' phase evolution and residual stress. The microstructural analysis and the phase diagram in Fig. 4 will help evaluate the soundness and defect structure of the joints and optimize the process parameters. Vickers microhardness will be measured, and the fracture toughness (K_{IC}) will be estimated using standard relations based on the hardness measurements.

Deliverables: The microstructural data obtained from SEM, TEM, and Raman will help optimize the EFAJ process parameters and quality control of the joints. This task will continue until the end of the project period.

Task 4 Mechanical Testing of EFAJ Ceramic Joints: The cylindrical joints' shear strength will be tested at room temperature using a universal testing frame (Instron, model 5967 with a 5 kN and a 10 kN load cell) available at CAES. Fig. 6 schematically illustrates the shear testing arrangement. Self-aligning fixtures will be machined, and cylindrical EFAJ samples will be inserted into the fixture jaws. Each jaw travels in the opposite direction at a predetermined speed (< 0.1 mm/minute). The joint line will be aligned at the interface of the moving jaws. The shear strength of the joint will be calculated from the breaking load and the cross-section of the joint. All the tests will be carried out at room temperature. The EFAJ process will be optimized to achieve the shear strength of the joint equivalent to that of the parent material.

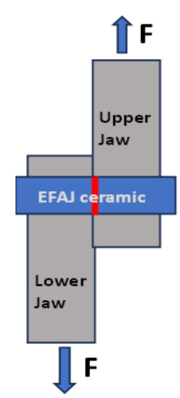

Fig. 6 Shear testing of EFAJ ceramic sample.

Deliverables: Shear strength data of the EFAJ processed joints of SiC-SiC, ZrB2-ZrB_2, and SiC-ZrB_2 with and without surface modifications. This task will continue until the end of the project period.

Alignment with Idaho HERC Priorities: The proposed project focuses on the advanced manufacturing of complex components for the energy sector, including nuclear and fossil fuels. The current TRL is 2. A successful proof-of-concept demonstration will raise it to TRL 4.

7. Potential Economic Impact

7.1 Commercial Potential: The lack of a robust joining technique limits the potential use of thermal shock-resistant ceramic materials in aggressive environments, ranging from nuclear power generation to defense applications. The silicon carbide market was valued at USD 3.1 billion in 2023 and is anticipated to grow at a CAGR of over 30% between 2024 and 2032. The demand for ultra-high-temperature ceramics will be 362.3 billion dollars in 2025, with a CAGR of 16% [[18]]. Establishing a joining technique that seamlessly matches the parent ceramic material's properties will attract federal and private funding. Several current generation and advanced nuclear reactors, including micro and modular reactors, use SiC components where joining is crucial. The investigators are collaborating with Dr. Mitchelle Meyer of NuCube Energy to develop a solid-state direct welding process for joining complicated SiC components. The University of Idaho has signed an NDA with NuCube Energy and partnered with them to submit a DOE-SBIR proposal. This concept has great potential for generating intellectual property. Based on the preliminary test results, the investigators will write several research grants seeking funding from federal and private agencies to translate the laboratory-scale joining process to the pilot-scale process to execute the joining of more complex configurations at a larger scale.

7.2 Economic Impact: Advanced ceramic materials such as β-SiC and ZrB_2 are used in critical energy, defense, and aerospace applications such as advanced nuclear reactors, rocket cones, leading edges of wings, etc. Joining ceramic components is still challenging for the widespread use of advanced ceramic materials. For example, for the successful development of SiC-based fuel cladding, joining the cladding to the end plug is recognized as a technological hurdle. The successful demonstration of the proof of concept of this project will be a game changer and lead to several patents. The proposed technology is easily scalable and will attract funding from several sources. If a local business like NuCube Energy is involved in this project and transforms the technology into a manufacturing unit, it will generate a significant employment opportunity for Idaho and impact the local economy.

8. Criteria for Measuring Success

Success will be measured based on achieving the milestones and meeting the timelines, which are given in section 12—Project Management. The primary criterion is to develop the EFAJ process using surface-modified mating surfaces that equal the shear strength of the parent material. An additional metric for measuring the project's success will be the submission of at

[18] https://www.strategymrc.com/report/ultra-high-temperature-ceramics-uhtc-market - retrieved on 10/17/2024.

least two manuscripts to refereed journals for publication. Another metric for success is the submission of a research grant proposal to a federal agency seeking additional funding to expand the proof of concept to the pilot scale. The current TRL is 1-2. The successful completion of the project will make the TRL 3 or 4. If we reach TRL 4, the project will be highly successful. Two graduate students will be supported in this project for 2 semesters and complete most of their requirements to graduate with their M.S. degrees.

9. Anticipated Development Challenges and Mitigation Strategies

Other researchers with limited success have demonstrated the EFAJ process on unmodified surfaces due to the poor plastic deformation behavior of the ceramic materials. To overcome this limitation, this project utilizes modified surfaces with the termination of one kind of constitutive atom on the mating surfaces. Reactive bonding is anticipated when the two atomic surfaces are combined. Therefore, the primary challenge is to modify the surface with the desired termination of atoms. We will employ two methods to have the desired surface terminations described in Task 1. If one method does not work, the other method will be tried. Since most surface modification techniques have been successfully demonstrated for different applications, as discussed in the Task 1 background, we do not anticipate any barriers that cannot be overcome.

10. Budget: The budget spreadsheet is included in Appendix D of this document.

11. Budget Justification

The table below provides an itemized budget for the proposed project, which will run from July 1, 2025, to June 30, 2026 (12 months).

LINE ITEM REQUEST	JUSTIFICATION	TOTAL REQUEST
Personnel (salary and fringe)	Salary support for PI, co-PI and two graduate students	107311.16
Equipment	None	
Travel	None	
Participant Support	None	
Other Direct Costs	Materials, supplies, tuition, and student health insurance	50,183.92
Total		157,500

The explanation of costs indicated in the budget above is as follows:

Personnel Costs (salary and fringe): PI Raja and co-PI Charit will spend one summer month each working on the project. Two graduate students will execute the project tasks for 12 months. The salary and fringe bases are shown in section 10. Per the university guidance on new proposals, anticipated rates as 'estimated fringe rates' for projects beginning 7/1/25 and later are applied. FY26 anticipated fringe rates are as follows: Faculty: 29.5%; Staff: 40.1%; and Students: 3.2%. Other direct costs include supplies cost of $20,000 (cost of ceramic materials ($3200), machining and surface modification ($9000), fixtures for shear testing ($2800), gases and other supplies ($3050), and analytical & characterization user facility charges ($65/sample for 30 samples = $1950)), publication costs of $2590, and graduate students tuition ($5732 per student per semester, total $

22930) and health insurance ($1166 per semester per student, total $ 4664) for 2 students, 3 semesters.

12. Project Management

Timeline

Task	Description	Project timeline months											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Task 1 Surface modification												
2.	Task 2 EFAJ												
3	Task 3 Microstructure												
4	Task 4 Shear Testing												

Milestone 1: Preparation of surface modified samples by the end of 4th month
Milestone 2: Delivery of EFAJ samples for characterization at the end of 7th month
Milestone 3: Optimized EFAJ samples of at least one material at the end of 9th month
Milestone 4: Shear test results of the EFAJ samples of at least one material at the end of 10th month.

PI Raja will serve as the overall project director and will be the lead responsible for tasks 1 and 2. Co-PI Charit will lead the experimental efforts on tasks 3 and 4. Two graduate students will conduct the project activities, with the PI and co-PI serving as one student's major professor/advisor. The research group will hold biweekly meetings to review the activities and analyze the data. In addition, both PI and co-PI will be available and accessible to both the graduate students for consultation and discussion as needed. PI and co-PI have collaborated extensively on several research projects and developed a smooth *modus operandi* to accomplish project objectives successfully.

13. Additional Institutional and Other Sector Support: The project's institutional support manifests in the availability of lab space, utilities, and project administration support.

14. Future Funding: Several avenues are identified for securing funding for future research and technology development. These include federal funding agencies and industrial partnerships. Federal funding agencies/programs that sponsor research include the Department of Energy, NSF, and Department of Defense units such as DARPA and AFSOR. We collaborate with small businesses to submit SBIR/STTR proposals. The investigators are collaborating with Dr. Mitchelle Meyer of NuCube Energy to develop a solid-state direct welding process for joining complicated SiC components. The University of Idaho has signed an NDA with NuCube Energy and partnered with them to submit a DOE-SBIR proposal. We will continue collaborating with other small businesses (a support letter is included in Appendix D) and submit SBIR/STTR proposals. The proof of concept of this proposal will help explore further funding opportunities to expand to the next TRL level and ultimately reach commercialization by teaming up with a large-scale manufacturing industry.

Appendix A: Facilities and Equipment

Dr. Raja has the following facilities available in his laboratory:
(1) Material preparation: A planetary ball mill for preparing the FeCr and Fe-B matrix as shown in Fig. 3, A controlled atmosphere glove box capable of maintaining < 0.2 ppm oxygen and

Fig. 3. Images of the planetary ball mill for preparation of the alloy matrix.

Fig. 4 Controlled atmosphere glove box that can maintain oxygen and moisture less than 2 ppm.

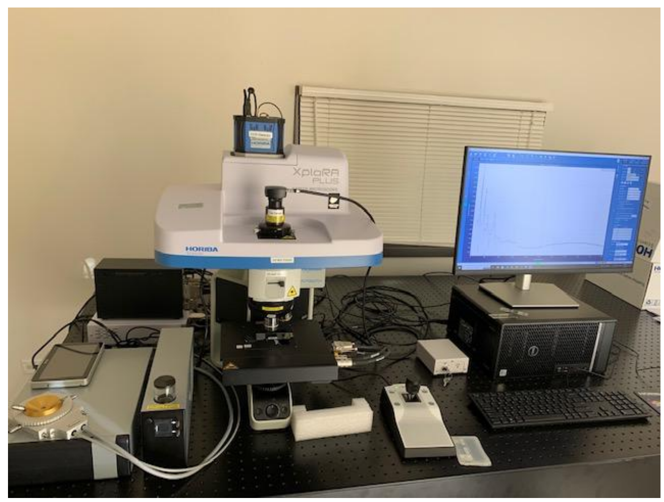

Fig. 54 Confocal Raman Microscope (Horiba, XPloRA Plus) with a Linkam Hot stage. Raman spectra can be obtained in- situ while heating the samples to 1100 °C

moisture

(mBraun, Model: LabStar) (Fig. 4), several potentiostats (Gamry Instruments, Models: Reference 600 and Interface 1000, Princeton Applied Research (AMETEK), Model: VersaSTAT MC (4-channels), and CH Instruments: Model 400C Electrochemical quartz microbalance). Seven experiments can be carried out at the same using the potentiostats.
(2) Material Characterization: **Confocal Raman Microscope, Make: HORIBA, Model: XPloRA** Plus with LINKAM Hot stage capable of heating molten salts to 1100 °C in an argon atmosphere and conducting in-situ microscopy (Fig. 5). Three laser wavelengths 532, 638, and 785 nm each 100 mW, motorized stage capable of mapping the sample (3) Spectroscopic Facility: Raman spectrometer (i-Raman with 532 nm laser, Gamry Instruments) and in-situ UV-Vis spectroscope (Spectro 115E, 350-1050 nm, Gamry Instruments) for in-situ spectroscopic investigation during electrochemical testing. (4) Thermal treatment facilities: Two controlled atmosphere furnaces

with ramping capabilities with a maximum temperature of 1300 ºC (Nabertherm, Model: RD/30/200/13) and 1700 ºC (SentroTech, Model STT-1700C), Vacuum Oven: (Max: 250 ºC, 1 cu.ft., V0 – 0.1 MPa Vacuum reading, Jeio Tech Co., Model: OV-11-120). (5) Other experimental testing facilities: Microbalance (Radwag USA, Model: XA110/2X), and Millipore water purification system capable of supplying high purity water with 18.2 Megaohm-cm resistivity, several non-destructive testing capabilities including ultrasonic flaw detector (GE Inspection Technologies, Model: USM Go), Eddy current tester, magnetic flux detector. An ICP-MS (Shimadzu ICPMS 2030) is available in the department with unlimited access for analyzing liquid and gaseous samples.

Dr. Charit has a 5982 model Instron universal tester for carrying out high temperature tensile tests (fitted with Epsilon Technologies 3549 high temperature extensometer) and an Applied Test Systems 2335 lever arm (20:1) creep tester for performing high temperature creep tests. Both instruments are fitted with furnaces capable of reaching 1000 ºC. In addition, a LECO LM-100 microhardness tester is available for doing Vickers microhardness testing. Dr. Charit's laboratory also has a Netzsch Simultaneous Thermal Analyzer (capable of simultaneously performing three thermal analysis techniques, differential scanning calorimetry (DSC), differential thermal analysis (DTA) and thermogravimetric analysis (TGA) up to 1500ºC, high temperature furnaces including one MHI furnace capable of going up to 1700oC, ball milling equipment (SPEX Mill 8000M), SPEX 2380 bench press, glove box, a complete TEM sample preparation kit (Gatan Disc Punch, Fischione Disc Grinder and Twin-Jet Polisher), and a metallography facility (Buehler precision saw, an Allied HighTech TwinPrep grinder/polisher, a Pace Technologies hot mounting press, a vibratory polisher and an Amscope optical microscope).

The university investigators have access to various other advanced characterization instruments located at the Center for Advanced Energy Studies (CAES) such as Microstructure and Characterization Suite (MaCS), and Advanced Materials Laboratory (AML) The MaCS is a state-of-the-art microstructural characterization facility housed inside the having the following instruments: Scanning Transmission Electron Microscope (STEM) - ThermoFisher Spectra 300 - monochromated, double-corrected, 30 - 300kV; Scanning Transmission Electron Microscope - FEI Tecnai TF30-FEG STwin TEM with EDS, EELS (GIF), EFTEM & TopSpin; Dual Beam Focused Ion Beam Microscope (FIB) - FEI QUANTA 3D FEG with EDS & EBSD; Scanning Electron Microscope (SEM) - JEOL JSM 6610LV with EDS, EBSD, & CL; Local Electrode Atom Probe (LEAP) - Cameca LEAP 4000X HR; Nano Indenter Atomic Force Microscope - Hysitron TI950 TriboIndenter; X-Ray Diffractometer (XRD) - Rigaku SmartLab.

Appendix B : Biographical Sketches

IDENTIFYING INFORMATION:

NAME: Raja, Krishnan Selva

ORCID iD: https://orcid.org/0000-0003-4746-2272

POSITION TITLE: Professor of Nuclear Engineering

PRIMARY ORGANIZATION AND LOCATION: University of Idaho, Idaho Falls, Idaho, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Indian Institute of Technology, Chennai, Not Applicable, N/A, India	PHD	07/1993	Welding and Stress Corrosion Cracking-Metallurgical Engineering
Indian Institute of Technology, Chennai, Not Applicable, N/A, India	MENG	02/1988	Industrial Metallurgy
College of Engineering, Guindy (Anna University), Chennai, Not Applicable, N/A, India	BENG	05/1986	Mechanical Engineering

Appointments and Positions

2023 - present	Professor of Nuclear Engineering, University of Idaho, Idaho Falls, Idaho, United States
2021 - 2022	Professor of Materials Engineering, University of Idaho, Moscow, Idaho, United States
2016 - 2021	Associate Professor, Materials Engineering, University of Idaho, Moscow, Idaho, United States
2011 - 2016	Assistant Professor of Materials Engineering, University of Idaho, Moscow, Idaho, United States
2001 - 2011	Research Faculty - Chemical and Materials Engineering, University of Nevada, Reno, Nevada, United States
1997 - 2000	Research Associate, Tohoku University, Sendai, Not Applicable, N/A, Japan
1993 - 1997	Research Executive Engineer, Larsen & Toubro Ltd., Mumbai, Not Applicable, N/A, India

Products

Products Most Closely Related to the Proposed Project

1. Day B, Zillinger J, Utgikar V, Raja K. The Electrochemical Behavior of Tellurium Tetrachloride in LiCl-KCl Eutectic Molten Salt at 450 ºC. Journal of The Electrochemical Society. 2021 May 18; 168(5):056514-. Available from: https://iopscience.iop.org/article/10.1149/1945-7111/abfeff DOI: 10.1149/1945-7111/abfeff
2. Balumuru C, Raja K, Sabharwall P, Utgikar V. Adsorption of Radioactive Iodine Using Nanocarbon on ETS-10 as Adsorbent. Nuclear Technology. 2024 April 12; :1-9. Available from:

https://www.tandfonline.com/doi/full/10.1080/00295450.2024.2329834 DOI: 10.1080/00295450.2024.2329834

3. Sitler S, Raja K, Charit I. Hot corrosion behavior of ZrB2-HfB2 solid solutions in KCl and K2SO4 at 1500 °C. Ceramics International. 2017 December; 43(18):17071-17085. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0272884217320515 DOI: 10.1016/j.ceramint.2017.09.122
4. Pesic B, Battick F, Raja K. Conductivity enhancement of yttria doped ceria by spark plasma and ac assisted sintering methods. Canadian Metallurgical Quarterly. 2013 November 18; 52(3):295-302. Available from: http://www.tandfonline.com/doi/full/10.1179/1879139513Y.0000000077 DOI: 10.1179/1879139513Y.0000000077
5. Thuneman T, Raja K, Charit I. Room Temperature Corrosion Behavior of Selective Laser Melting (SLM)-Processed Ni-Fe Superalloy (Inconel 718) in 3.5% NaCl Solution at Different pH Conditions: Role of Microstructures. Crystals. 2024 January 18; 14(1):89-. Available from: https://www.mdpi.com/2073-4352/14/1/89 DOI: 10.3390/cryst14010089

Other Significant Products, Whether or Not Related to the Proposed Project

1. Naskar A, Bhattacharyya M, Jana S, Darsell J, Raja K, Charit I. Chloride-Induced Stress Corrosion Cracking of Friction Stir-Welded 304L Stainless Steel: Effect of Microstructure and Temperature. Crystals. 2024 June 16; 14(6):556-. Available from: https://www.mdpi.com/2073-4352/14/6/556 DOI: 10.3390/cryst14060556
2. Goettsche H, Raja K, Sabbarwall P, Utgikar V. Effects of moisture and aging upon decomposition of methyl iodide by reduced silver mordenite. Adsorption. 2024 April 21; :-. Available from: https://link.springer.com/10.1007/s10450-024-00473-8 DOI: 10.1007/s10450-024-00473-8
3. Singla Y, Miller J, Raja K, Maughan M. Toward single crystal nickel fabrication using WAAM – A first report. Journal of Materials Research and Technology. 2023 November; 27:4801-4804. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2238785423027898 DOI: 10.1016/j.jmrt.2023.11.016
4. Bare W, Struhs E, Mirkouei A, Overturf K, Chacón-Patiño M, McKenna A, Chen H, Raja K. Controlling Eutrophication of Aquaculture Production Water Using Biochar: Correlation of Molecular Composition with Adsorption Characteristics as Revealed by FT-ICR Mass Spectrometry. Processes. 2023 September 30; 11(10):2883-. Available from: https://www.mdpi.com/2227-9717/11/10/2883 DOI: 10.3390/pr11102883
5. Vaidya T, Stanford J, Rooyen N, Raja K, Utgikar V, Sabharwall P. Capture of Volatile Organic Iodine Species Using Mordenites. Journal of Nuclear Fuel Cycle and Waste Technology(JNFCWT). 2023 June 30; 21(2):205-224. Available from: https://www.jnfcwt.or.kr/journal/article.php?code=86875 DOI: 10.7733/jnfcwt.2023.016

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Raja, Krishnan Selva in SciENcv on 2025-02-06 22:47:42

IDENTIFYING INFORMATION:

NAME: Charit, Indrajit

ORCID iD: https://orcid.org/0000-0002-3854-2900

POSITION TITLE: Professor and Department Chair

PRIMARY ORGANIZATION AND LOCATION: Department of Nuclear Engineering and Industrial Management, University of Idaho, Idaho Falls, Idaho, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Missouri University of Science and Technology, Rolla, Missouri, United States	PHD	05/2004	Metallurgical Engineering
Indian Institute of Science, Bangalore, Not Applicable, N/A, India	MENG	01/2000	Metallurgy
Indian Institute of Engineering Science and Technology, Shibpur, Not Applicable, N/A, India	BENG	06/1997	Metallurgical Engineering

Appointments and Positions

2021 - present Professor and Department Chair, Department of Nuclear Engineering and Industrial Management, University of Idaho, Idaho Falls, Idaho, United States

2020 - present Affiliate Professor, Department of Mechanical Engineering, University of Idaho, Moscow, Idaho, United States

2010 - present Affiliate, Center for Advanced Energy Studies, Idaho Falls, Idaho, United States

2023 - 2023 Interim Center Executive Officer, University of Idaho - Idaho Falls Center, Idaho Falls, Idaho, United States

2020 - 2020 Professor and Director, Materials Science and Engineering Program, University of Idaho, Moscow, Idaho, United States

2019 - 2020 Professor, Department of Chemical and Materials Engineering, University of Idaho, Moscow, Idaho, United States

2015 - 2020 Director of Graduate Studies, Department of Chemical and Materials Engineering, University of Idaho, Moscow, Idaho, United States

2013 - 2019 Associate Professor, Department of Chemical and Materials Engineering, University of Idaho, Moscow, Idaho, United States

2010 - 2013 Assistant Professor, Department of Chemical and Materials Engineering, University of Idaho, Moscow, Idaho, United States

2008 - 2008 Visiting Faculty, Materials and Fuels Complex, Idaho National Laboratory, Idaho Falls, Idaho, United States

2007 - 2010 Assistant Professor, Department of Materials Science and Engineering, University of Idaho, Moscow, Idaho, United States

2005 - 2007 Postdoctoral Research Associate, Department of Nuclear Engineering, North Carolina State University, Raleigh, North Carolina, United States

2004 - 2004	Postdoctoral Fellow, Department of Materials Science and Engineering, Missouri University of Science and Technology, Rolla, Missouri, United States
2000 - 2004	Graduate Research Assistant, Department of Metallurgical Engineering, Missouri University of Science and Technology, Rolla, Missouri, United States
2000 - 2000	Project Engineer, TVS Suzuki Limited, Hosur, Not Applicable, N/A, India
1997 - 1998	Quality Control Engineer, Electrosteel Castings Limited , Khardah, Not Applicable, N/A, India

Products

Products Most Closely Related to the Proposed Project

1. Bhattacharyya M, Kundu A, Raja KS, Charit I, Darsell JT, Jana S. Microstructure-Property Correlations for Temperature-Controlled Friction Stir Welding of 304L SS Plates. Materials Science and Engineering A. 2021; 804(21):140635. Available from: https://doi.org/10.1016/j.msea.2020.140635
2. Ghayoor M, Mirzababaei S, Sittiho A, Charit I, Paul BK, Pasebani S. Thermal Stability of Additively Manufactured Austenitic 304L ODS Alloy. Journal of Materials Science and Technology. 2021; 83:208-218. Available from: DOI: 10.1016/j.jmst.2020.12.033
3. Goel S, Sittiho A, Klement U, Joshi S, Charit I. Effect of Post-Treatments under Hot Isostatic Pressure on Microstructural Characteristics of EBM-built Alloy 718. Additive Manufacturing. 2019; 28:727-737. Available from: https://doi.org/10.1016/j.addma.2019.06.002
4. Brubaker N, Ali H, Dhakal S, van Rooyen N, Jaster M, Charit I, Jaques B, Maughan MR. Investigating Microstructure and Properties of 316L Stainless Steel Produced by Wire-Fed Laser Metal Deposition. Journal of Materials Engineering and Performance. 2022; 31:3508-3519. Available from: https://doi.org/10.1007/s11665-021-06477-7
5. Roberts D, Zhang Y, Charit I, Zhang J. A Comparative Study of Microstructure and High Temperature Mechanical Properties of 15-5 PH Stainless Steel Processed via Additive Manufacturing and Traditional Manufacturing. Progress in Additive Manufacturing. 2018; 3(3):183-190. Available from: https://doi.org/10.1007/s40964-018-0051-5

Other Significant Products, Whether or Not Related to the Proposed Project

1. Khanal R, Ayers N, Jerred N, Benson MT, Mariani RD, Charit I, Choudhury S. Role of Zr in Lanthanides-Dopants Interactions within Uranium-Based Metallic Fuels. Nuclear Materials and Energy. 2021; 26:100912. Available from: https://doi.org/10.1016/j.nme.2021.100912
2. Jerred ND. Nd, SbNd, and Sb3Nd4, and their interactions with the cladding alloy HT9. Journal of Nuclear Materials. 2020; 541:152387. Available from: https://doi.org/10.1016/j.jnucmat.2020.152387
3. Jerred N, Charit I, Zirker L, Cole J. Pressure Resistance Welding of MA-957 to HT-9 for Advanced Reactor Applications. Journal of Nuclear Materials. 2018; 508:265-277. Available from: https://doi.org/10.1016/j.jnucmat.2018.05.046
4. Charit I, Mishra RS. Effect of Friction Stir Processed Microstructure on Tensile Properties of an Al-Zn-Mg-Sc Alloy upon Subsequent Aging Heat Treatment. Journal of Materials Science and Technology. 2018; 34:214-218. Available from: https://doi.org/10.1016/j.jmst.2017.10.021
5. Shrestha T, Basirat M, Alsagabi S, Sittiho A, Charit I, Potirniche GP. Creep Rupture Behavior

of Welded Grade 91 Steel. Materials Science and Engineering A. 2016; 669:75-86. Available from: https://doi.org/10.1016/j.msea.2016.05.065

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Charit, Indrajit in SciENcv on 2025-02-07 19:01:30

Appendix D: OTHERS

Project Title: Joining of Non-oxide Ceramic Components Used in Extreme Envir

Milestone description (if applicabl *Enter milestone number and/or brief description here*

Insert more rows in each section, as needed. *Copy/paste cell formulas, as needed.* *See cell notes for additional information.*

Do not remove or hide rows. *Shaded areas have preset formulas.*

Personnel

Name	FTE (opt	Months	Base Salary	Salary Reques	Fringe Rate	Other Ben Ra	Fringe Reque	Total
Krishnan S Raja		1	$125,814.00	$13,979.33	0.295		$4,123.90	**$18,103.24**
Indrajit Charit		1	$153,784.80	$17,087.20	0.295		$5,040.72	**$22,127.92**
Graduate Student - 1		12	$32,500.00	$32,500.00	0.032		$1,040.00	**$33,540.00**
Graduate Student -2		12	$32,500.00	$32,500.00	0.032		$1,040.00	**$33,540.00**
		1	$0.00	$0.00			$0.00	**$0.00**
		1	$0.00	$0.00			$0.00	**$0.00**
								$107,311.16

Equipment

Item Description	Units	Unit Cost	Total
	1		**$0.00**
			$0.00

Travel

Tentative Date(s)	# person	Total days	Transit cost/ pers	Lodging/ day	Meal per diem	Total
						$0.00
						$0.00

Participant Support

Description	# person	Cost/ Stipend	Total
			$0.00
			$0.00

Other Direct Costs

Item	Units	Cost	Total
Materials/ Supplies	1	$20,000.00	**$20,000.00**
Publication Charges	1	$2,590.00	**$2,590.00**
Consultants (add consultant travel here)	1		**$0.00**
Computer Services	1		**$0.00**
Subcontract 1	1		**$0.00**
Subcontracts 2			**$0.00**
Other (list specifics if over $1,000)	1		**$0.00**
In-state tuition for 2 grad students for two	4	$5,732.48	**$22,929.92**
Health insurance for 2 grad students for 1 year	4	$1,166.00	**$4,664.00**
Other	1		**$0.00**
			$50,183.92
TOTAL DIRECT COST REQUEST			**$157,495.08**

GenNEXT Materials
& TECHNOLOGIES

February 23, 2025

John Thomas
HERC Program Manager
Idaho State Board of Education
650 West State Street, 3rd Floor
Boise, ID 83702

Subject: Letter of support for the University of Idaho's HERC project entitled, "Joining of Non-Oxide Ceramic Components Used in Extreme Environments."

Dear Mr. John Thomas and Members of the Higher Education Research Council:

GenNext Materials & Technologies, LLC (GMT), is currently collaborating with Drs. Raja and Charit on an STTR Phase I project funded by the U.S. Department of Energy (USDOE) entitled "3D Printing of Functionally Graded in-situ Sacrificial Anode Claddings for Enhanced Corrosion and Irradiation Resistance in MSR Applications".

GMT understands that Drs. Raja and Charit are submitting a proposal titled "Joining of Non-Oxide Ceramic Components Used in Extreme Environments." The proposed approach of rendering the mating surfaces with the termination of selective atoms will help achieve high-strength joints at low temperatures. GMT realizes several potential commercial opportunities for this method.

If this proposal is funded, GMT will be very interested in exploring possible collaborations on the UofI's new approach and how it differs from the conventional techniques.

We will be delighted to help the team develop appropriate proposals through the SBIR/STTR Phase I or Phase II platforms in consultation with our current DOE Program Manager or other offices related to this topical area.

We wish the UofI team the very best with their submission.

Sincerely

S. Vaidyanathan
Vaidyanathan Subramanian
Managing Partner
GenNext Materials & Technologies, LLC (GMT),
Reno, Nevada
rsvgmt@gmail.com

NuCube Energy

NuCube Energy, Inc.
130 West Union Street
Pasadena, CA 91103

February 25, 2025

John Thomas
HERC Program Manager
Idaho State Board of Education
650 West State Street, 3rd Floor
Boise, ID 83702

Subject: Letter of support for the University of Idaho's HERC project entitled, "Joining of Non-Oxide Ceramic Components Used in Extreme Environments."

Dear Mr. John Thomas and Members of the Higher Education Research Council:

NuCube Energy is an innovative company that will transform how nuclear fission is used to power our society. NuCube is developing a new technology that, in its groundbreaking simplicity, will achieve the degree of affordability and safety that will make nuclear energy the natural complement for wind, solar, and energy storage, achieving a sustainable future for humankind.

NuCube understands that Drs. Raja and Charit are submitting a proposal titled "Joining of Non-Oxide Ceramic Components Used in Extreme Environments." NuCube submitted an SBIR proposal in collaboration with the University of Idaho on a similar topic focusing on joining SiC components for advanced nuclear reactors that NuCube is developing. This proposal appears to extend a similar approach to other ceramic materials, including zirconium boride.

If this proposal is funded, NuCube will work closely with the UI investigators to demonstrate the proof-of-the-concept and translate it to pilot-scale production. We will also help the team develop appropriate proposals for attracting funding from federal and private agencies.

NuCube is a incubated by IdeaLab (Pasedena, CA), however all technical activities are conducted in Idaho Falls, in close proximity to UI's Idaho Falls campus.

We wish the UI team good luck with their submission.

Mitchell K Meyer

Sincerely

Mitch Meyer, Ph.D.
Director, Nuclear Fuels and Materials
NuCube Energy, Inc.