***Establishing Modular In-Chamber Electron Beam Welding Capability in the USA"***

***PI: David Gandy, Marc Albert***
***Electric Power Research Institute, Inc. (EPRI)***

***Pathway: 2, Advanced Reactor Development Projects***

***Collaborators:***
***BWXT Nuclear, PTR-Precision Technologies, NuScale Power, Bridger Welding Engineering, Advanced Manufacturing Research Centre, Rusach International***

***Abstract***
Recent manufacturing and fabrication efforts for advanced light water reactors (ALWRs) in the United States have highlighted the need for new technologies and infrastructure to reduce production costs. To enable cost-effective development and deployment of small modular reactors (SMRs) and advanced generation nuclear units, the U.S. industry must consider advanced manufacturing/fabrication technologies and methods. This proposal presents a Modular In-Chamber Electron Beam Welding (MIC-EBW) approach that can be used to join large-diameter, thick-section components such as reactor vessels, steam generators, and pressurizers. Using this approach, component welds up to 10ft (3.05m) in diameter can potentially be completed in less than 90 minutes, compared to several weeks with conventional welding technologies. The MIC-EBW capability will be developed in collaboration with a major fabricator/manufacturer and demonstrated on 10ft (3.05m) diameter, thick-section vessel components. Upon completion, this project will demonstrate the capability to produce large, thick-section components to support new nuclear production in the United States.

In 2017, the U.S. DOE, in collaboration with EPRI, Nuclear AMRC, and NuScale Power, launched a project (DE-NE0008629) to manufacture and assemble several critical sections of a 2/3-scale reactor pressure vessel (RPV) using various advanced manufacturing and fabrication technologies, including EBW, diode laser cladding, powder metallurgy-hot isostatic pressing, and advanced machining. All EBW development/demonstration in the current project is being performed in a large EB vacuum welding chamber in the United Kingdom. No similar large-size EBW capabilities exist in the United States. For the United States to fully implement EBW of large-scale components, an even larger vacuum chamber (~35 ft long) would be required. This has led EPRI to propose the modular in-chamber EBW approach (MIC-EBW), which could be readily implemented by U.S. industry at considerably lower cost (~1/3rd). Five key objectives have been identified for this project:

- Develop and establish MIC-EBW capability at a major U.S. fabricator.
- Reduce overall welding arc time by up to 90% compared to conventional welding technologies used for vessel production.
- Successfully demonstrate a 10ft (3.05m) diameter, 4.375 inch (110mm) thick vessel EB weld in less than 90 minutes of welding time.
- Establish MIC-EBW capability to perform major RPV girth welds for the NuScale Power RPV.
- Develop manufacturing process plans based on the technology and required post-weld inspection/heat treatment.

**Project Scope and Tasks** In conjunction with NuScale Power, BWXT Nuclear, PTR-Precision Technologies (an electron beam welding equipment manufacturer), and other team members, the MIC-EBW capability will be designed, developed, and demonstrated to assemble thick-section [4.375 inches (110 mm)] vessel ring sections at both a medium diameter and scaled to a large diameter (10ft [3.05m]). The effort will include:

- Design and manufacture of an EB gun/slide module and three additional vacuum modules inwhich sections of the RPV will be demonstrated

- Production of vacuum pumping equipment, an EB power module, transformer, and controls
- Production of a large rotary table capable of rotating a vessel up to 175 tons (350,000 kg)
- Development of machining and phase array inspection knowledge and equipment
- Benchmarking and training of personnel to operate the system

The proposed MIC-EBW capability will be developed in two phases: (1) EBW Equipment Design and Production (currently in progress), and (2) Full-Scale Modular In-Chamber Welding Demonstration (the subject of this proposal). Phase 1 of the project is focused on detailed process planning for major elements of the MIC-EBW system/approach, including welding, inspection, and manufacturing. Two of the key elements of the EBW system have been designed and fabricated: a vacuum pumping system capability and an EB gun and slide that will be used to complete each of the major girth welds in the NuScale Power SMR reactor pressure vessel design. Phase 1 also includes the design of vacuum seals used to create a seal between modular sections of the MIC-EBW system, design of the major modules of the system, and a demonstration of the MIC-EBW technology on small diameter steel rings. Phase 1 was cost-shared with EPRI and NuScale Power.

Phase 2 of the project will include production of a large rotary table to rotate vessel sections during welding, production of four modules and a base section of the overall vacuum system, and demonstration of the MIC-EBW on a full-size RPV section (10-ft [3.05-m]). Additionally, Phase 2 will include development and demonstration of NDE methodologies for assessing the EB welds and benchmarking against weldments produced in a large fixed vacuum chamber in the UK. Phase 2 will be cost-shared with EPRI, NuScale Power, BWXT Nuclear, Advanced Manufacturing Research Centre, Fluor Marine Propulsion--Naval Nuclear Laboratory, and Doosan Heavy Industries & Construction.

**Project Impact/Outcomes** The proposed project will serve as a natural follow-on effort to: 1) the DOE/EPRI/Nuclear AMRC research on SMR Reactor Vessel Manufacturing and Fabrication project (DE-NE0008629) and 2) Establishing Modular In-Chamber EB Welding Capability in the USA for Large Scale Components—Phase 1 (DE-NE0008846). The project will significantly advance EBW technology for large component applications and, most importantly, establish large-scale EBW capabilities for pressure-retaining components in the USA. By reducing actual welding time for large-diameter welds from weeks to less than 90 minutes, the risks associated with commercialization of advanced nuclear technologies would be significantly reduced. Notably, the MIC-EBW technology could: be used by any manufacturer; accommodate modules of different sizes by detaching and re-attaching the EBW gun and slide; and be implemented across multiple industries, including oil and gas, wind energy, and ship-building.

**Project Deliverables** Phase 1: A process planning report that details all welding, inspection, and manufacturing steps associated with EB welding capability; manufacture of a triode EBW gun and slide; manufacture of a vacuum pumping system; development of vacuum sealing technology for large EB modules; and demonstration of EBW capabilities on 4ft (1.22m) diameter rings. Phase 2: Manufacture of a rotary manipulation stage (>175 ton [350,000 lb] capability); demonstration of large (10 ft [3.05 m] diameter), thick-section component EBW capability; demonstration that a large-diameter, thick-section weld can be completed in less than 90 minutes; development of machining and phased array inspection systems.

**Participants** Major participants in the project will include EPRI, NuScale Power, BWXT Nuclear, PTR-Precision Technologies, Advanced Manufacturing Research Centre (UK), Fluor Marine Propulsion, Bridger Welding Engineering, Doosan Heavy Industries and Construction, and Rusach International.