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Advancements Toward ASME Nuclear Code Case for Compact Heat Exchangers

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Program: Codification of Compact Heat Exchanger Usage for Nuclear Systems (IRP-RC-1)

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ABSTRACT:

Our research team proposes to advance the state of the ASME section III code (nuclear service) for Compact Heat Exchangers (CHX). This work will improve the technical state of CHXs and lay the foundation necessary for these heat exchangers to be certified for use in nuclear service. During the course of this work we will advance the understanding of the performance, integrity and lifetime of the CHXs for use in any industrial application, making their use more attractive and accessible to industry. We will do this by developing qualification and inspection procedures that utilize Non-destructive evaluation (NDE) and advanced in-service inspection techniques, with insight from the industrial utility leader EPRI. We have enlisted colleagues at MPR Associates (MPR), an elite nuclear code consulting firm, who are experts on the ASME section III code and who, with input from members of the ASME section III committee, will direct the testing and help develop a series of documents that define the rules and regulations for use of the CHX. Colleagues at North Carolina State University (NCSU) and Oregon State University (OSU) will conduct extensive tensile, creep and fatigue experiments on diffusion bonded samples (manufactured by US based Vacuum Process engineering) along with modeling using the elastic perfectly plastic assumptions and comprehensive full inelastic finite element analysis (FEA). This work will allow analysis by design and confidence in the strength of different internal structures. To ensure industry acceptance and long term confidence, team members at the University of Wisconsin–Madison (UW), University of Michigan (UM), Georgia Tech (GT) and the University of Idaho (UI) will extensively test prototypic heat exchangers manufactured by US-based manufactures CompRex and Vacuum Process Engineering (VPE), a leader in the development of advanced CHX. This testing will include the use of various working fluids (salt, sodium, helium and sCO_2) to evaluate operational issues as well as structural integrity under the most severe conditions. Post-test analysis of the tested CHXs coupled with pre/in-service/post NDE (ultrasonic and radiography) led by the Electric Power Research Institute (EPRI) will be incorporated into the development of the rules and regulations for their use in nuclear service.

Our proposal has one KEY goal, with several sub-objectives:

- **Enable the use of advanced manufactured compact heat exchangers in order to improve the efficiency and economics of advanced nuclear reactors.**

As discussed below, we will use information and data from several existing NEUP programs and we will leverage the code rules for section VIII and input from vendors and potential users of the compact heat exchangers to help develop rules and guidelines for their use in nuclear service. While it is not practical or

conceivable to develop the ASME section III code case (since the ASME committees are required to do this), we can and will interact substantially with the ASME section III subcommittee to develop data, documentation, and techniques that could be used by the committees to significantly shorten the time necessary for the codification of compact heat exchangers. This will be accomplished by first examining the section III rules and options for construction of compact heat exchangers, and then developing a roadmap tying those needs into the detailed tasks of the proposal. Overall concept and tasks are depicted in Figure 1 and the objectives for each task are listed below.

Objectives:

Task 1 Objectives:

- Develop rules and regulations for use of Compact heat exchangers for nuclear service.
- Advise and direct Tasks 2-5 to develop the needed information to inform and justify the rules and regulations.
- Meet with ASME code committee to draft code case.

Task 2 Objectives:

- Conduct tensile, creep, fatigue and creep-fatigue tests using uniaxial specimens machined from diffusion welded solid block to determine mechanical properties of the diffusion bond.
- Perform finite element analyses of the CHX cores to determine orthotropic elastic properties which will be used for evaluation of sidewall and header thermal stresses.
- Perform full inelastic finite analysis using an advanced unified constitutive model (UCM) to provide insight of the failure responses observed in the CHX experiments.
- Develop elastic perfectly plastic analysis methodologies for qualification of CHXs for nuclear application.

Task 3. Objectives:

- Define operating conditions for PCHEs in different nuclear reactor systems.
- Conduct Failure mode and effects Analysis (FMEA) on CHX for nuclear systems.
- Design and construct prototypical PCHEs for the different nuclear reactor applications using either the herringbone or marbond core geometry.
- Test prototypical small CHX under prototypical operating conditions associated with nuclear reactor systems (HTGR, VHTR, SFR, FHR,MSR).
- Test the effects of fouling in a CHX resulting from precipitation, particulate, chemical reactions, corrosion and solidification if these mechanisms are shown to occur in CHX using He, SCO_2 or Molten Salt.
- Test cleaning methods for CHX, including but not limited to, chemically cleaning and "reverse puffing."
- Perform CFD analysis to determine where and how crud is deposited in CHX and determine operational impairment based on crud deposition.

Task 4 Objectives:

- Develop a tool box of nondestructive evaluation (NDE) techniques for diffusion bonded CHX.
- Use standard techniques to evaluate Prototype CHX during construction, post construction.
- Assess techniques that would need further development for post and in-service inspection.

Task 5 Objectives

- Conduct burst, steady and cyclic pressure tests at high temperature on small CHX core specimens.
- Assess NDE tests with respect to burst tests.