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Final CRADA Report – NFE-21-08642 Multiphysics Design Optimization and Additive Manufacturing of Nuclear Components (Executive Summary)

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ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

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Nuclear Engineering and Fuel Cycle Division

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ABSTRACT

Westinghouse Electric Company (WEC) actively participated in the advancement of the nuclear fuel and reactor design space and requested the help of Oak Ridge National Laboratory (ORNL) in the creation of a new design tool set. This report details the creation of a collection of software tool sets that are linked together to collectively assist WEC design engineers in developing novel ideas outside the normal scope of traditional nuclear fuel and reactor design formulas. Specifically, Siemens HEEDS [1], a design space exploration and parametric optimization software, monitored and changed parameters in a collection of softwares to meet the team's objective. The HEEDS parametric optimization method, SHERPA, was developed to control the Siemens NX CAD [2] platform to adjust the native CAD of a hexahedral spacer grid. This new geometry can be used to execute a topological design optimization by the NX Topology software add-in [3]. The resulting geometry is additively manufacturable. This topological optimization occurred twice—once on the spacer grid's spring, and once on the dimple geometry. These new geometries were imported by Siemens' STAR-CCM+ [4], a multiphysics structural and fluid dynamic computational solver in which the spring geometry is deflected to match the rod insertion configuration. Along with the dimple geometry, this new deflected spring was used to complete a hydraulic assessment of a single-unit cell comprising one rod, one spring, and two dimples. The HEEDS SHERPA algorithm ranks the design based on the final mass of the unit cell and the hydraulic pressure drop performance. The ORNL team demonstrated the ability to use this software and provided engineering judgement to apply modern aerospace aerodynamic design. The effort has been focused on thinking outside the conventional design space and redesigning a spacer grid to perform beyond the WEC set objectives. Furthermore, the ORNL team also demonstrated that the HEEDS optimization routine can independently develop a design that meets the WEC design goals. Although these designs were at a low technology readiness level, their demonstration confirmed the team's capability to create novel advanced nuclear concepts.

1. STATEMENT OF OBJECTIVES

1.1 BACKGROUND

WEC is actively engaging in new design pathways in advanced fuels and reactors, including but not limited to accident-tolerant fuel (ATF), advanced fuel assemblies, micro-reactors, and high-capacity nuclear power plants (NPPs) based on lead fast reactor (LFR) technology. WEC invests new concepts to position themselves for the future by providing cutting edge modern designs. Thus, WEC is considering advanced manufacturing methods such as additive manufacturing (AM), as well as advanced engineering design capabilities such as high-performance computing (HPC) and modern design optimization (e.g., traditional parametric and generative/topological optimization), which was recently deployed in the AM design process. These combined work scopes allow WEC to develop a new pathway for designers to think more creatively outside the traditional modern design process, thus improving overall NPP performance and cost efficiency.

2. THE BENEFITS OF FUNDING THE DOE OFFICE'S MISSION

A design pathway that empowers nuclear design engineers to creatively explore novel design concepts using modern computing resources and design techniques to leverage AM printing capabilities provides innovation for current light-water reactors and the entire advanced reactor space. Combining multiple design optimization methodologies with the forethought to implement AM technologies to explore beyond the boundaries of conventional design processes will prompt rapid modernization of the aging nuclear fuel and reactor design space. Furthermore, it will accelerate the processes that typically take years by enlisting a large team dedicated to the design pathway, shortening the timeline and reducing personnel cost.

3. CONCLUSIONS

In this project, Westinghouse Electric Company (WEC) sought a new design tool kit to help think outside the box regarding current spacer grid design by removing conventional design thought-process limitations to allow for a reduced hydraulic pressure drop and reduced material usage. The Oak Ridge National Laboratory team demonstrated this capability from two different pathways. The first pathway included using Siemens NX Topological optimization and engineering adjustments based on WEC's design specifications and common aerodynamic design principles. The second pathway included development of a parametric design optimization routine within Siemens HEEDS to create and evaluate potential designs from the NX Topology add-in. This routine was checked for viability within NX and Siemens STAR-CCM+. Although the programs performed nearly the same in reducing the overall mass needed with approximately 40% of the starting spacer grid mass, the human intervention of modern aerodynamic design outperformed the HEEDS design hydraulically. Although the HEEDS design was able to meet the hydraulic performance goals, the aerodynamic design further reduced the hydraulic pressure loss by a factor of 4. Suggestions are provided to help bring the HEEDS design routine closer to the human engineering intervention. It is recommended that WEC continue enhancing the HEEDS routine as suggested herein. Ultimately, the designs provided should be considered a starting point from which experienced engineers can further evaluate and adjust as needed.