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Parallel Algorithms and Software for Nuclear, Energy, and Environmental Applications. Part II: Multiphysics Software

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Abstract. This paper is the second part of a two part sequence on multiphysics algorithms and software. The first [1] focused on the algorithms; this part treats the multiphysics software framework and applications based on it. Tight coupling is typically designed into the analysis application at inception, as such an application is strongly tied to a composite nonlinear solver that arrives at the final solution by treating all equations simultaneously. The application must also take care to minimize both time and space error between the physics, particularly if more than one mesh representation is needed in the solution process. This paper presents an application framework that was specifically designed to support tightly coupled multiphysics analysis. The Multiphysics Object Oriented Simulation Environment (MOOSE) is based on the Jacobian-free Newton-Krylov (JFNK) method combined with physics-based preconditioning to provide the underlying mathematical structure for applications. The report concludes with the presentation of a host of nuclear, energy, and environmental applications that demonstrate the efficacy of the approach and the utility of a well-designed multiphysics framework.

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1 Introduction

This paper describes an evolving software framework MOOSE [2] which utilizes the algorithmic framework presented in Part I [1] to enable rapid development of multiphysics engineering analysis tools. Further, it presents several applications based on the MOOSE framework that support high fidelity analysis of various nuclear, energy, and environmental problems.

BISON [3] is a nuclear fuel performance code that is designed to analyze how fuel behaves within a nuclear reactor. It is a fully coupled multiphysics application that combines thermomechanics of the fuel and protective cladding material with specialized models that describe how the fuel (and cladding) ages as it is subjected to thermal stresses and irradiation. This fuel performance application is particularly interesting in that it is also a fully coupled multiscale application. This analysis capability employs a separate calculation at a much lower length scale (the *mesoscale*) that computes how the fuel material behaves under irradiation conditions, and how the thermal conductivity, stress, and strain behaves at this scale. This information is then bridged up to the BISON finite element code to describe the bulk fuel behavior. The model is strongly coupled in that the thermal profile of the fuel (calculated at the large scale) affects the susceptibility of the fuel material to irradiation processes.

PRONGHORN [4] is a reactor core simulator for Pebble-Bed Reactors (PBRs) that models neutronics, fluid dynamics, and heat conduction within the solid components of the reactor. It is also a fully coupled application that examines the dynamics of these three coupled effects in reactor geometry.

FALCON is under development to support the analysis of geothermal reservoirs and geothermal systems, and considers multiphase fluid flow, energy transport, and deformation of the subsurface in such systems. RAT is also a subsurface analysis code designed to simulate single phase flow and reactive geochemistry. Both of these applications are designed for fully coupled simulation and use the MOOSE framework.

This part begins with a description of the MOOSE framework.

2 Software and results

2.1 MOOSE

The Multiphysics Object Oriented Simulation Environment is a computational framework created at the Idaho National Laboratory to enable rapid development of new sci-