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Modeling K-DEMO Plasma Power Exhaust with UEDGE; a Status Report (through Oct. 2018)

T. D. Rognlien

November 6, 2018

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T.D. Rognlien

Lawrence Livermore National Laboratory, Livermore, CA 94550 USA

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Disclamer

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I. Overview of Project

The goal of this project is to develop simulation capability for the edge plasma region of K-DEMO [1] in order to assess the heat and particle loads on plasma facing components. The roles of Lawrence Livermore National Laboratory (LLNL) are to provide the UEDGE simulation code for this purpose, to obtain initial edge-plasma solutions for K-DEMO, and to train K-DEMO staff members in both the use of the 2D UEDGE and the code structure such that future modification can be made. A schematic of K-DEMO highlighting the power exhaust is shown in Fig. 1. The major radius of the device is 6.8 m, and the total power to be exhausted is 280 MW in the edge plasma region. Evaluating impact of different divertor geometries and the use of seeded impurity radiation to manage the peak heat flux to surfaces are key aspects being addressed.

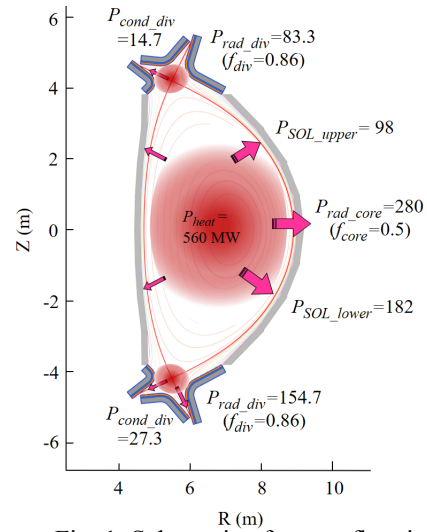

Fig. 1 Schematic of power flow in K-DEMO from Ref. [1].

II. Introduction to UEDGE

The LLNL participants have served as the primary developers of the 2D UEDGE plasma transport code [2,3]. UEDGE implements a multi-species fluid model, solving the plasma density, the ion and electron velocities, and the ion and electron temperatures in the full toroidal geometry of 2D magnetic equilibria. The most important empirical input to UEDGE is the anomalous radial transport coefficients, which can be represented by spatially varying diffusion and convection coefficients. The neutral gas model generally used in UEDGE is a fluid neutral description for atomic species and, for hydrogen, a molecular species. This model is efficient and well-adapted to the high density, short mean-free path regime that arise for reactor conditions where charge-exchange and elastic scattering among other neutrals and ions is strong. This neutral model is periodically calibrated with more detailed Monte Carlo neutral simulations using DEGAS 2 [4]. Impurity ions and neutrals are also included, giving power loss from line radiation as well as fuel (deuterium/tritium) fuel dilution. To account for kinetic effects, the models include a flux-limited form of the classical parallel transport coefficients for ions and electrons calibrated by kinetic calculations as well as for neutral transport in the low-density periphery. The output from UEDGE includes plasma heat and particle fluxes to all surrounding surfaces, including the divertor and main-chamber walls. Varying shapes of divertor surfaces are accommodated directly via a body-fitting mesh capability, and single-null and double-null divertor configurations can be simulated. Both transient and steady-state simulations can be performed.

UEDGE has previously been used to model the particle and heat fluxes to plasma-facing components in reactor-scale devices. These studies have been published and detailed results can be found for the ACT-1 reactor design in Ref. [5] and the Fusion Nuclear Science Facility (FNSF) study in Refs. [4,6]. Both of these studies utilized highly radiating divertor plasmas through moderate-Z impurity injection with various divertor geometries.

III. K-Demo work progress through October 2018

Prior to the visit by Drs. Lee and Kwon to LLNL in August, 2018, the K-DEMO team sent us a typical magnetic equilibrium (MHD) file for K-DEMO. We developed an appropriate input file for UEDGE using this magnetic equilibrium that defines the computation mesh and found a steady-state plasma/neutral solution for generic set of input parameters taken from Ref. [1].

- LLNL demonstrated the basic capability of UEDGE to model K-DEMO edge and scrape-off layer regions.

Drs. Lee and Kwon visited LLNL from August 20-28, 2018. We provide office space and internet connection for them throughout the visit. Two UEDGE specialists, Tom Rognlien and Bill Meyer, worked with Drs. Lee and Kwon daily during this period. A list of activities is as follows:

- Provided a static version of the UEDGE executable that could run on the NFRI unix system where Dr. Lee began to perform simulations.
- Installed the same version of UEDGE on Dr. Kwon's Mac laptop and taught him how to perform UEDGE simulations there.
- Instructed Drs. Lee and Kwon on how to edit the input file for UEDGE so that different input parameters (e.g., exhaust power, core-edge density, radial anomalous transport coefficients, impurity level, divertor plate tilt etc.) could be varied to under their impact on particle and heat fluxes.
- Provided various documents the describe the various features of UEDGE, including a 100+ page UEDGE manual, shorter MS Word demonstrating the typical execution procedure including restarts from previous cases, and figures illustrating how the cell indexing maps to the physical domain.
- Guided Drs. Lee and Kwon through their first UEDGE simulations for K-DEMO, showing them how to obtain steady-state solutions, how to save the final state for later analysis, and how to write out quantities of interest to ascii files that can then be read and plotted in their favor plotting routine. Also illustrated the internal UEDGE plotting package.
- This initial simulate work resulted in Drs. Lee and Kwon obtaining steady-state solutions for both a flat-plate divertor and then for the strongly tilted divertor plate envisioned for K-DEMO. For example, the initial flat-plate divertor solutions yield electron temperature values illustrated in Fig. 2. This is an example of a radiative divertor solution with 0.4% neon added to the deuterium/tritium fuel. The peak heat flux on walls and divertor is < 2 MW/m^2, and ~70% of the input power is radiated by neon.

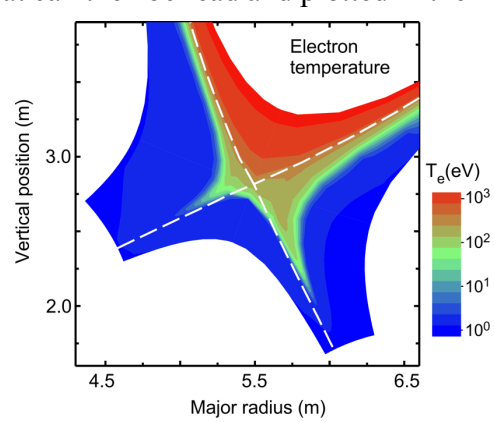

Fig. 2 Electron temperature contours in K-DEMO divertor from UEDGE; flat plates.

During September and October of 2018 following Drs. Lee and Kwon's first visit, LLNL continued work to make continuing updates to UEDGE available to our K-DEMO colleagues and to accelerate the completion of the Python version of UEDGE. A new Python version of UEDGE

is now available. Both Python and the older Basis systems are frameworks that offer very versatile ways to run, steer, and diagnose UEDGE, but the advantage of Python is that it is available and supported for almost any computer platform, whereas Basis is not. This Python version will thus enable the K-DEMO team to modify the UEDGE source and recompile on almost any computer platform. UEDGE itself remains written in Fortran. In summary, the September/October progress impacting the K-DEMO work are as follows:

- The current UEDGE source files are now generally downloadable through GitHub at https://github.com/LLNL/UEDGE with an LGPL open-source license.
- The conversion of UEDGE to run under Python and to be compiled with gfortran was accelerated to be available for Drs. Lee and Kwon's November visit and has been completed. Thus, the UEDGE source can now be modified, rebuilt, and run under many different computer platforms, allowing flexibility for adding new models.
- Demonstrated that the previous K-DEMO solutions obtained during Drs. Lee and Kwon's August visit yield the same plasma/neutral solutions under the UEDGE Python version.

IV. K-Demo work for the remainder of the contract period

Drs. Lee and Kwon will visit LLNL again during Nov. 19-30, 2018 to continue to learn more details about how to use the Python UEDGE, make changes to the UEDGE source code, and perform more complex simulations of K-DEMO. They will again be assisted by Tom Rognlien, Bill Meyer, and perhaps other members of our Theory and Simulation Group. The tasks for this visit is as follows:

- Learn to download, build, and run the Python UEDGE suite on multiple platforms, e.g, the NFRI unix system, Mac laptop, and maybe PC.
- Perform more extensive K-DEMO simulations with Python UEDGE and learn how to diagnose and display output.
- Learn more details on the structure of UEDGE, practice making source-code changes, and rebuilding UEDGE

Finally, as agreed to in our contract with NFRI, we will:

- Provide a final report on the accomplishments of our work.

References

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