LA-UR-15-27579
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Title:	Analysis of Performance of Selected AFC, ATF Fuels, and Lanthanide Transport
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Intended for:	DOE Milestone Report
Issued:	2015-09-29

Appendix E
FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	Analysis of performance of selected AFC, ATF fuels, and lanthanide transport
Work Package Title and Number	M3FT-15LA0204091
Work Package WBS Number	FT-15LA020409
Responsible Work Package Manager	Cetin Unal [signature] (Name/Signature)

Date Submitted 9/22/2015

Quality Rigor Level for Deliverable/Milestone ☒ -QRL-3 ☐ QRL-2 ☐ QRL-1 ☐ Nuclear Data ☐ N/A*

This deliverable was prepared in accordance with LANL (Participant/National Laboratory Name)

QA program which meets the requirements of

☒ - DOE Order 414.1 ☐ NQA-1-2000 ☐ Other

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Analysis of Performance of Selected AFC, ATF Fuels, and Lanthanide Transport

Cetin Unal and Jack Galloway

Summary of accomplishments

We started to look at the performance of ATF concept in LWRs late in FY14 and finish our studies in FY15. The work has been presented in AFC review meetings, ICAPP and TOPFUEL conferences. The final version of the work is accepted for publication in Nuclear Engineering and Science Journal (NES). The copy of ICAPP and NES papers are attached separately to this document as our milestone deliverables.

We made an important progress in the modeling of lanthanide transport in FY15. This work produced an ANS Winter Meeting paper and GLOBAL 2015 paper. GLOBAL 2015 paper is also attached as deliverable of FY15. The work on the lanthanide transport is preliminary. We are exploring other potential mechanisms, in addition to "liquid-like" diffusion mechanisms, proposed by Robert Mariani [1] before we analyze data that will be taken by Ohio State University. This year, we concentrate on developing diffusion kernels and principles of modeling. Next year, this work will continue and analyze the Ohio State data and develop approaches to solve multicomponent diffusion.

In addition to three papers we attached to this report, we have done some research on coupling and the development of gas release model for metallic fuels in FY15. They are also preliminary in nature; therefore, we give the summary of what we found rather than an extended report that will be done in FY16.

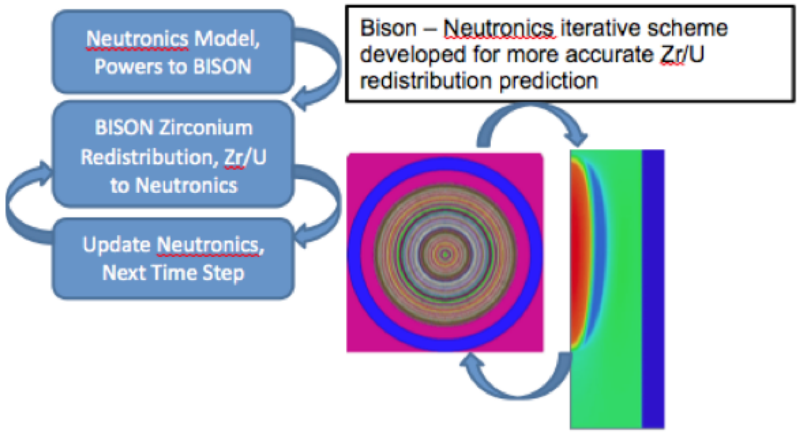

Figure 1- The sketch of Bison-neutronics coupling.

At the beginning of this fiscal year, we coupled Bison with a neutronics and burnup simulation code for more accurate power distribution estimation. First solving for the power distribution in the neutronics code, the power distribution was then overlaid on the Bison simulation for a given time step (see Figure 1). Subsequently, the Bison model solved for the Zirconium redistribution (and conversely the Uranium redistribution) which was then passed back to the neutronics/burnup simulation to progress the solution over the next time step. This simulation process was carried out for both experimental data sets, T179 and DP16. The results shown in Figure 2 are for DP16, a 485 day irradiated U-Pu-Zr-MA fuel. The "coupled" results show the final solution when including the iterative process between the neutronics code and Bison, while the "no coupling" results use a correlation to Zr concentration to estimate the power fraction. While the temperature profile is not drastically different, the Zr redistribution model is very sensitive to slight temperature changes due to the near step function changes at phase boundaries in the ternary fuel; thus, the slight temperature changes result in distinctly different Zr redistribution predictions. The same trend observed here was seen for T179, albeit much less pronounced, due to the drastically shorter irradiation time for T179 (92 days versus 485 days for DP16).

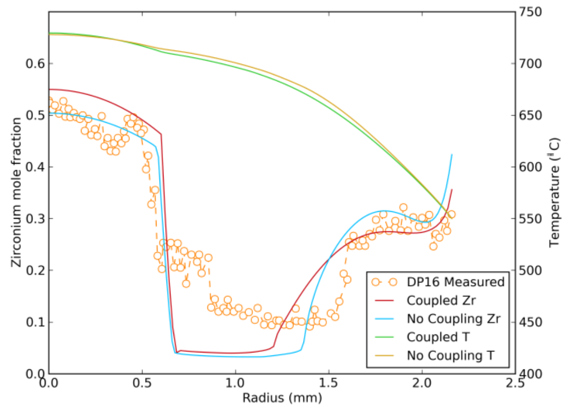

Figure 2. DP16 Zirconium and Temperature Distribution - End of Cycle.

Additionally, this fiscal year, a metallic fission gas release model (based upon the GRSIS [2] model), was implemented in Bison furthering the pursuit comprehensive metallic fuel performance code in the Bison framework (implementation shown in Figure 3).

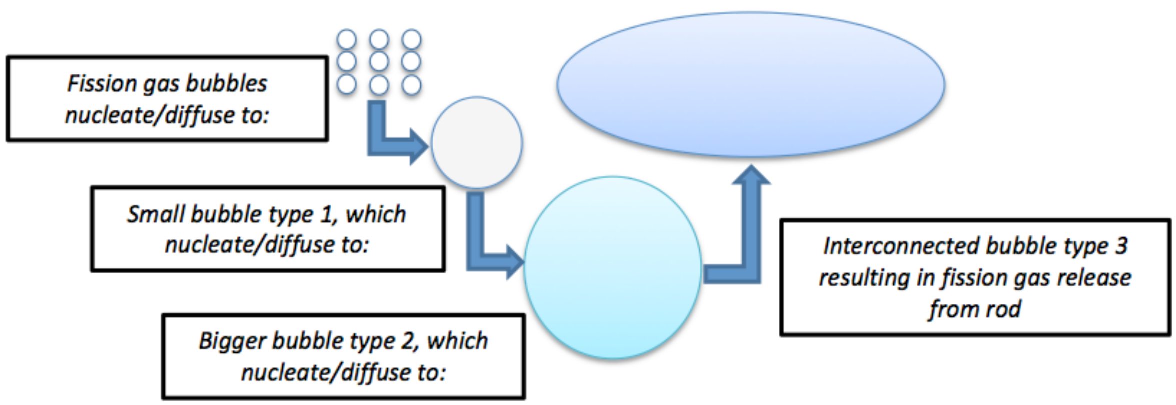

Figure 3. Metallic Fission Gas Release Approach.

This model assumes two bubble sizes prior to interconnection and the initiation of fission gas release. Fission gas atoms are created in the fuel matrix where they can either stay in the fuel matrix, diffuse to existing bubbles, or nucleate new bubbles. Bubbles grow from a smaller size to a larger size before a critical swelling threshold is reached, bubble interconnection is assumed, and the fission gas is released from the fuel. This fission gas release model was found to have many input parameters, some of which were observed to be quite insensitive to the solution. Additionally, the stability of the solution to the time step size (dt) was observed to be quite high, requiring a fairly small dt, on the order of 30 – 100 seconds, to achieve similar solutions. Figure 4 shows this time step sensitivity. Up until approximately ten days, no fission gas is released; whereupon, the critical swelling threshold is reached and fission gas is released from the matrix. Using a dt of 10,000 seconds, the solution rapidly encountered numerical instability and promptly crashed. A subsequent decrement of dt to 1,000, then 100, and finally 30 seconds, is shown for comparison. While there is a drastic difference (and underestimate) of the fission gas release at a dt of 1,000 seconds compared to 100 seconds, the shape and magnitude of 100 and 30 seconds is quite similar. A final simulation that solved both the fission gas release fraction and the Zr distribution was performed and compared against the same solution without Zr redistribution to assess the sensitivity. Figure 5 shows the comparison where much less fission gas is observed to be released for the same problem when the Zr is allowed to migrate. This is most likely due to the different power profile; thus, different temperature distribution in the fuel as a result of the migrating Uranium (opposite the Zr migration). Further development of the fission gas release model, with a focus on a more robust numerical scheme is needed. The variable nature of the fission gas release estimate when coupled with Zr redistribution highlights the importance of a continued pursuit of a robust, multi-physics, metallic fuel performance code.

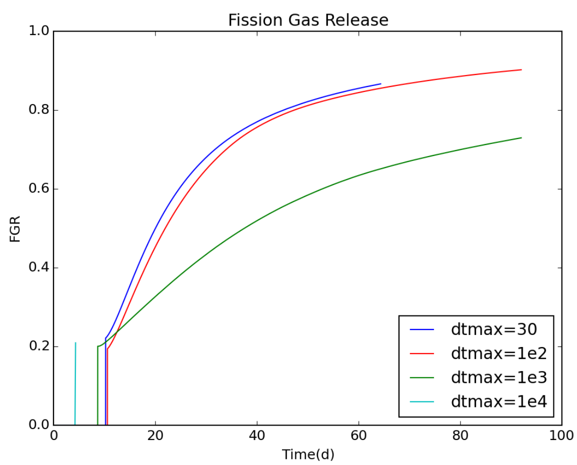

Figure 4. Metallic Fission Gas Release Model - dt Sensitivity & Zr.

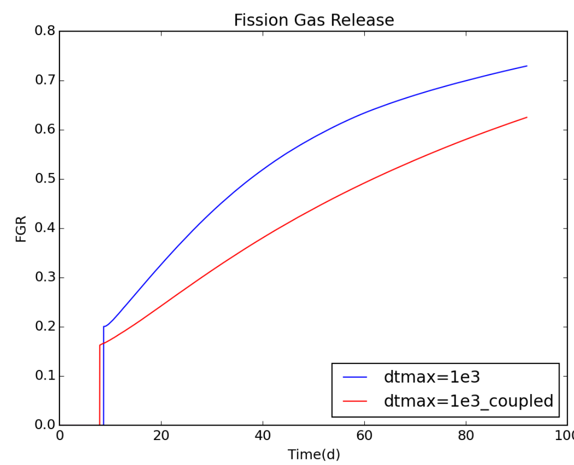

Figure 5. Fission Gas Release With and Without Zirconium Redistribution.

Finally, this fiscal year, we also showed proof of principle coupling of Bison with the transient analysis code TRAC. Taking a representative EBR-II bundle with a random power distribution across the 61 fuel pins, swinging +/15% from nominal rod power, we simulated each rod with coupled Zirconium redistribution and used TRAC to solve for the convective heat transfer coefficient. Here, we took the fuel surface temperature distribution from Bison and fed it into TRAC, returning from TRAC the heat transfer coefficient (HTC) and bulk coolant temperature distribution. Figure 6 shows the 61 pin layout for the simulation. Solving each pin in 2D-RZ, full length geometry, the evolving Zr distribution and associated power peaking was solved for. In Zr dominant regions, the power drops significantly, while increasing significantly in the Zr vacant regions. This work showed a proof of principle calculation coupling TRAC in a steady state simulation. Lastly, the Zr redistribution and temperature distribution are shown for a representative rod, one arbitrarily selected from the bundle model, in Figure 7.

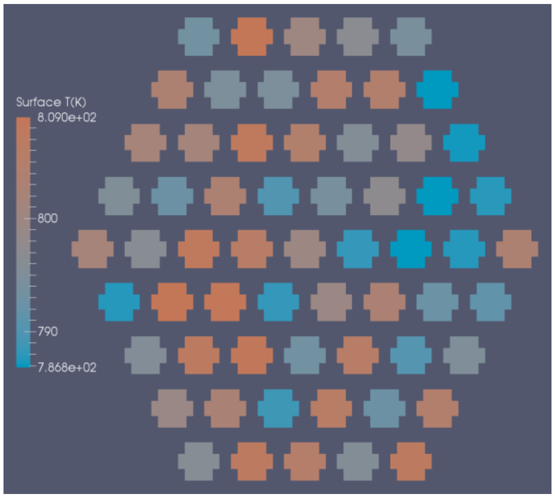

Figure 6. EBR-II Bundle Fuel Surface Temperature Variation.

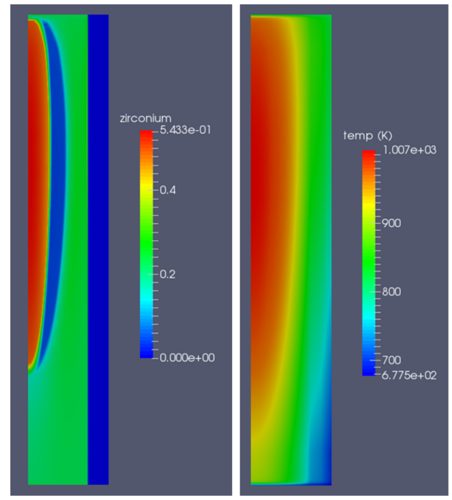

Figure 7. Zirconium Redistribution & Temperature Profile for Representative Rod.

References

1. R. Mariani, D. Porter, T. O. Holleran, S. Hayes, J. Kennedy, "*Lanthanides in metallic nuclear fuels: Their behavior and methods for their control*", Journal of Nuclear Materials 419 (1-3) (2011) 263-271. doi:http://dx.doi.org/10.1016/j.jnucmat. 2011.08.036.
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2. C. B. Lee et al., "Fission Gas Release and Swelling Model of Metallic Fast Reactor Fuel," Journal of Nuclear Materials, Vol. 288, pp.29-42, (2001).