Task 4.a: Analysis Capability Development – Fuel Performance

The Nuclear Regulatory Commission's (NRC's) fuel performance codes, FRAPCON and FRAPTRAN, which are currently being merged into a single code called "FAST," will need to be updated to conduct analysis of accident tolerant fuel (ATF) fuel performance and support licensing reviews. Fuel performance codes are needed to support licensing review because they are used to demonstrate that specified acceptable fuel design limits (SAFDLs) are maintained and to provide initial conditions for design-basis accident analysis. Additionally, fuel performance codes are used to support the safety limits for loading and storing spent nuclear fuel in dry casks.

Fuel performance code updates needed to model some ATF designs, including FeCrAl cladding and coated zirconium-based alloy claddings, will require minimal changes to FAST, with the work focused on new material properties and code assessment and benchmarking. Updates needed to model SiC tubing, any non-UO_2 fuel, and metallic fuel in non-cylindrical fuel forms, would be more extensive. FAST development activities include the following tasks:

Scoping Study – For FAST, this will be a low resource, straight forward activity because the code development needs are largely understood.

Code Architecture Updates – For FAST, this includes modifying the code to be more modular. The staff will remove any computational assumptions embedded in the code for the Zirconium/UO_2 system and ensure that the heat transfer, solid mechanics, and diffusion solutions are generic while calling a separate set of libraries (MatLib) containing the relevant material properties. The staff will modify FAST to allow for modeling non-cylindrical fuel forms which entails re-solving the physics modeled by the code (e.g., heat conduction, diffusion, solid mechanics, etc.) with different geometrical conditions and possibly modeling in multi-dimension. Finally, infrastructure development will include changes necessary to allow for interaction with other NRC tools via the SNAP interface.

Property and Model Development – Material properties (non-irradiated and irradiated) for ATF claddings and fuels will be added to MatLib (the material properties library in FAST), as well as models to address new phenomenon and failure modes presented by ATF. There are a series of thermal, mechanical, and irradiation-induced properties that need to be updated for each new fuel and cladding material. For new fuels, additional considerations include fission gas release and fuel creep. For claddings, additional correlations are needed to model hydrogen pickup, steady-state and transient corrosion, thermal and irradiation creep, high-temperature deformation, and new failure models. As experience is gained through use of ATF fuel and cladding in-reactor, it is expected that significant data will be available to the NRC to develop models that capture how the properties evolve as a function of burnup (e.g., thermal conductivity degradation). It is expected that additional properties will be needed to model new materials that are yet unknown, such as the diffusion of oxygen or volatiles, and fuel/cladding/coolant interaction, which may require more extensive modifications to both MatLib and FAST. As the phenomena becomes known, models related to long-term spent fuel handling, storage, and transportation will be updated.

Code Assessment and Validation – Integral performance data from Advanced Test Reactor (ATR), Halden, Transient Reactor Test Facility (TREAT) and LTA programs, as well as other available sources, will be used to confirm that the material properties and models added to FAST fully account for the integral behavior of ATF. This will be the most time-consuming task for several reasons. The focus of code assessment will need to be determined based on licensing requirements for each ATF design. For example, the current assessment of FAST for steady-state calculations looks at fission gas release, fuel centerline temperature, cladding strain, oxidation, and rod internal pressure, all of which are part of the SAFDLs outlined in NUREG-0800, Section 4.2, "Fuel System Design." The code assessment, also referred to as the Integral Assessment, analyzes the integral effects of all of the models and correlations working together to analyze the thermal-mechanical behavior of the fuel rod under typical light water reactor conditions. A proper assessment requires numerous cases that cover the breadth of boundary conditions and operating regimes that the fuel design will experience under normal operation, anticipated operational occurrences (AOO), and design-basis accident (DBA) conditions. For example, the FAST integral assessment currently consists of 176 non-proprietary cases for the uranium dioxide/zirconium system and numerous proprietary cases and data sets that the code (and its predecessor codes) has been assessed against over the last several decades. The integral assessment is the key to identify phenomena that may not be properly modeled. If discrepancies are shown between the code and the data, then the code's models and correlations will be re-examined and updated as necessary to achieve reasonable agreement. This will require an iteration between architecture updates (if new physics are determined to occur), material properties updates, and re-running of the integral assessment. In addition, the more detailed the integral assessment is, the more knowledge is gained on understanding the uncertainties of the code. The amount of data that is available to create the assessment database greatly affects the uncertainty of the results of analyses from the fuel performance codes. As more data is included in the assessment database, the confidence in the results of the analyses increases. As the size of the assessment database increases topical report reviews will become more efficient because there will be less uncertainty in the results of the fuel performance codes.

The milestones are listed in the tables below with their related trigger or needed input, lead time, and schedule driver

“Evolutionary” ATF concepts (e.g., coated cladding, doped pellet, FeCrAl)

Activity	**Data Needs and Inputs**	**Duration**	**Needed By**
Scoping Study	Low level of resources needed; short duration task		
Code Architecture Updates	-	1 year	-
Material Property and Model Development	Separate Effects Data	2 years	-
Code Assessment and Validation	Integral Effects Data	1 year	Fuel Topical Report Submittal
Lead Time for Fuel Performance Analysis Capability for Evolutionary ATF	2-4 years		

"Revolutionary" ATF concepts (e.g., SiC, U_3Si_2, metallic pellets, or solid rods)

Activity	Data Needs and Inputs	Duration	Needed By
Scoping Study	Low level of resources needed; short duration task		
Code Architecture Updates (Remove Zr and UO_2 hard-wired properties)	-	1 year[1]	-
Code Architecture Updates (Remove assumptions related to fuel geometry and Zr-UO_2 interaction)	Completion of previous milestone	2 years[2]	-
Material Property and Model Development	Separate Effects Data available	2-4 years[2]	-
Code Assessment and Validation	Integral Effects Data	2-3 years	Fuel Topical Report Submittal
Lead Time for Fuel Performance Analysis Capability for Revolutionary ATF	4-5 years		

[1] Task will not be required if the "evolutionary" activities are completed
[2] Tasks can be worked in parallel

Technical Lead: RES/DSA/FSCB