Task 4.d: Analysis Capability Development – Source Term

The primary severe accident related regulations affected by the use of the fuel include siting (Title 10 of the *Code of Federal Regulations* (10 CFR) Part 100) and safety analyses (10 CFR Part 50.34), control room radiological habitability, technical support center radiological habitability, equipment qualification, and combustible gas generation. Design-basis accident source term calculations are used to establish the adequacy of siting for commercial nuclear power plants and to ensure that adequate radiation protection exists for the control room and technical support center. Plants must ensure that they can handle combustible gas generation resulting from clad oxidation. Core degradation behavior, fission product release and timing, and combustible gas generation rate and quantity could all differ for different accident tolerant fuel (ATF) designs. The regulation at 10 CFR 50.67, "Accident Source Term," allows licensees to voluntarily revise the accident source term used in design basis radiological consequence analyses. Regulatory Guide 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," provides guidance to licensees and NUREG-0800, Chapter 15.0.1, "Radiological Consequence Analyses Using Alternative Source Terms," provides guidance to NRC staff on applications to revise the source term.

Scoping Study – A review of the current capabilities of the MELCOR code is needed to better understand the necessary code modifications in the code packages for the simulation of accident progression (i.e., core heat up and degradation, combustible gas generation, and fission product release and transport to the containment).

Code Architecture Updates – The required infrastructure development activities for MELCOR involve code modifications identified in the scoping study for implementation of new and/or improved models. MELCOR contains various models for the modeling of the core components (e.g., fuel, cladding, and channel boxes), hydrogen and carbon monoxide generation and combustion, and fission product release from the core components. Some models and correlations (for fission product release and core degradation) in the code need to be modified for application to new fuel designs (e.g., through access to sensitivity coefficients and control functions or through generalized models). Examples include fuel rod collapse and eutectic interactions (e.g., impact of Zr-Cr intermetallic reactions), and the oxidation kinetics of cladding based on experimental data (at high temperature and pressure). The material properties for new designs also need to be added to the code database.

Property and Model Development - It is expected that clad coatings would affect oxidation behavior/combustible gas generation rate, and that fuel composition would affect fission product release rates and potentially chemical speciation. There could also exist other potential effects such as chemical reactions between fuel and clad that accelerate or retard core degradation or between fission products and clad or fuel that could either enhance or diminish the release of fission products. The code should be able to account for fission product speciation under various conditions, and information from experiments on fission product release (for non-UO_2 fuel only) are needed for the development of the source term and code assessment.

The MELCOR code is well suited for developing a regulatory source term with flexible models to support evaluation of differences between current standard fuel and ATF concepts. The models existing in MELCOR are general in nature and can be adjusted to reflect differing properties of advanced fuels. Depending on results, the ATF models would likely be similar to those for standard fuel but with different parameters. Containment combustible gas control would need to be based on the expected release from the fuel/cladding combination based on the clad type. For Lightbridge (or other future designs using metal fuel), the contribution of the fuel itself to gas generation may need to be considered.

Code Assessment and Validation - Code verification and validation are important elements of the MELCOR software quality assurance program. All new code models need to be assessed against available test data. Experiments characterizing clad oxidation and combustible gas generation rates, fission product release magnitudes, and chemical forms and rates are required to ensure that the release models for ATF are representative and that such effects are accounted for, if significant.

Source Term Development - The process for developing radiological source terms involves: gathering of this experimental data; development and implementation of applicable models in the MELCOR code; simulating a series of accidents representing most of the core damage frequency for both boiling water reactors (BWRs) and pressurized water reactors (PWRs) to obtain fission-product-group-specific release behavior (i.e., “gap” and early in-vessel fission products release initiation time and duration, core release fraction and chemical forms); and finally collapsing the data into a simplified representative set of release fractions and timings for rapid use in simplified codes used for siting evaluation. As an example, the source term analysis for high-burnup and mixed-oxide fuel[1] was time consuming and involved about 30 detailed code calculations for BWRs and PWRs representing various accident scenarios (e.g., station blackouts, small and large break loss-of-coolant accidents).

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

[1] SAND 2011-0128 - Accident source terms for light-water nuclear power plants using high-burnup or MOX fuel

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

Activity	Data Needs and Inputs	Duration	Needed By
Scoping Study	Short duration task		
Code Architecture Updates	Completion of previous milestone	1 year[1]	-
Model Development	Separate Effects Data	1 year[1]	-
Code Assessment and Validation	Integral Effects Data	1 year[1]	-
Lead Time for MELCOR Analysis Capability for Evolutionary ATF	1 year		
Accident Progression Calculations with MELCOR	MELCOR code	1 year[2]	Safety Analysis Submittal
Lead Time for Source Term Development for Evolutionary ATF	2 years[3]		

[1] Tasks can be worked on in parallel (involves different phenomenology)
[2] Task can be worked on after completion of MELCOR analysis capability
[3] Includes the time for MELCOR capability and calculations

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

Activity	Data Needs and Inputs	Duration	Needed By
Scoping Study	Short duration task		
Code Architecture Updates	Completion of previous milestone	1 years[1]	-
Model Development	Separate Effects Data	2 years[1]	-
Code Assessment and Validation	Integral Effects Data	2 years[1]	-
Lead Time for MELCOR Analysis Capability for Revolutionary ATF	2-3 years		
Accident Progression Calculations with MELCOR	MELCOR code	2-3 years[2]	Safety Analysis Submittal
Lead Time for Source Term Development for Revolutionary ATF	4-6 years[3]		

[1] Tasks can be worked on in parallel (benefits from work done for evolutionary designs)
[2] Task can be worked on after completion of MELCOR analysis capability
[3] Includes the time for MELCOR capability and calculations

Technical Leads: RES/DSA/FSCB