DRAFT PROJECT PLAN TO PREPARE THE U.S. NUCLEAR REGULATORY COMMISSION TO LICENSE AND REGULATE ACCIDENT TOLERANT FUEL

The Offices of Nuclear Reactor Regulation (NRR), New Reactors, Nuclear Material Safety and Safeguards (NMSS), and Nuclear Regulatory Research (RES) are preparing for anticipated licensing and use of accident tolerant fuel (ATF) in United States commercial power reactors.

Several fuel vendors, in coordination with the Department of Energy (DOE) have announced plans to develop and seek approval for various fuel designs with enhanced accident tolerance (i.e., fuels with longer coping times during loss of cooling conditions). The designs being considered in the development of this plan include Cr coated claddings, Cr-doped UO_2 pellets, FeCrAl cladding, SiC cladding, U_3Si_2 pellets, and metallic fuels. For these ATF designs, the time frames for initial irradiation of lead test assembly (LTA) programs and topical report (TR)/license amendment request (LAR) review were used as a basis for the timelines discussed in this plan.

The NRC has entered into a memorandum of understanding (MOU) with DOE to collaborate on the nuclear safety research of enhanced ATFs that will reduce duplication of efforts and make the appropriate data available for regulatory decision processes. In preparing the agency to conduct meaningful and timely reviews of these advanced fuel designs, the NRC is conducting advanced planning, reviewing the existing regulatory infrastructure, and identifying needs for additional analysis capabilities, and the development of unique critical skillsets within the staff.

This project plan outlines the preliminary strategy for preparing the NRC to license ATF designs. It also identifies the lead organization for each planned activity. The project plan does not cover existing licensing activities, as they follow existing processes for which schedules and regulatory approaches are well-established.

Current preparation for ATF licensing is focused on light water reactor (LWR) fuel for the operating fleet. There may be synergies between LWR ATF fuel development and fuel safety qualification of some types of non-LWR fuels for advanced reactor designs. As appropriate, the NRC will leverage any synergies to help optimize licensing efficiency and effectiveness.

This project plan is expected to be a living document that may evolve as ATF concepts are more clearly defined and schedules for lead test assemblies (LTAs) and batch loading are refined.

ASSUMPTIONS

Major assumptions made during the development of this plan include:

1. The NRC will not perform independent confirmatory testing for specific ATF designs. It is expected that all necessary data needed to develop models will come from DOE, industry, or other organizations. Additionally, it is expected that all integral fuel behavior data will be provided to the NRC in a timely manner such that integral assessment of NRC codes can be performed.

2. Interaction with DOE, Electric Power Research Institute (EPRI), vendors, and other organizations involved in ATF-related experimental programs will take place in real-time and, whenever possible, in advance of experiments being conducted.
3. Interactions with external stakeholders will keep the staff and stakeholders informed about both technical and programmatic developments affecting activities identified in this project plan.

OPEN ITEMS

At the time of drafting of this plan, the NRC identified issues requiring further discussion with external stakeholders. This plan will be updated accordingly, as the following open items are addressed:

1. Identify whether, and if so what, regulatory guidance needs to be generated to accommodate licensing ATF designs under the current regulatory framework.
2. Establish channels of communication to ensure that the NRC continues to receive up-to-date information from DOE, industry, and other organizations.
3. Determine appropriate vehicles for industry to notify the NRC of intent to initiate specific activities.
4. Identify what, if any, other changes to the existing regulatory infrastructure may be necessary for ATF. For example, if probabilistic risk assessment (PRA) licensing approaches are going to be pursued by industry, robust interaction with stakeholders regarding Title 10 of the *Code of Federal Regulations* (10 CFR) 50.69 will need to take place (in advance of license applications) to ensure the regulatory framework is in place to support the approach.
5. Explore how early engagement in devising and conducting experimental research may expedite licensing timelines.

STAKEHOLDER INTERACTIONS

Key meetings and interactions scheduled during the development and review of ATF designs are outlined in Table 1. The primary risks to timely licensing of ATF relate to current uncertainties in the schedules for necessary experimental programs. The staff intends to remain closely engaged with the organizations and entities acquiring data and adjust the plan as new information becomes available. Another potentially significant risk to the successful implementation of ATF is a delayed recognition that changes to the regulations or regulatory guidance are required. The staff has initiated dialogue with stakeholders to communicate timelines required for various modifications to the regulatory infrastructure and to solicit input for changes that may be necessary for the different ATF concepts being explored.

Meetings, Stakeholder Interactions, and Critical Skill Development

- The NRC is committed to engaging in industry project update meetings and supporting NRC staff participation in experimental program discussions to maintain awareness of industry and DOE efforts and prepare for regulatory reviews.
- The NRC will develop staff and contractors with critical skills required to support projected applications of high to moderate certainty.
- All stakeholder interactions will occur in accordance with NRC's public meeting policy.

Table 1. Meetings and Stakeholder Interactions

Meeting	Frequency	Desired Outcome
EPRI/DOE/Idaho National Lab (INL) Update Meetings	Biannually	Assess the technical progress of ATF research and development (R&D); Obtain information necessary for developing analytical capabilities and licensing strategies.
TOPFUEL (rotates between US, Europe, and Asia)	Annually	Assess the technical progress of ATF R&D; Obtain information necessary for developing analytical capabilities and licensing strategies.
Enlarged Halden Program Group	Every 18 months	Assess the technical progress of ATF R&D; Obtain information necessary for developing analytical capabilities and licensing strategies.
ATF standards and guidance development activities with Orgnisation for Economic Co-operation and Development (OECD)/Nuclear Energy Agency (NEA), International Atomic Energy Agency (IAEA), and international counterparts	Annually	Discuss licensing approach with international counterparts.
Fuel Vendor Update Meetings (rotates from NRC HQ to vendor HQ)	Annually (per vendor)	Assess the technical progress of ATF R&D; Obtain information necessary for developing analytical capabilities and licensing strategies. (In addition to a number of other non-ATF outcomes).
ATR/TREAT Test Planning/ Test Observation Meetings	Annually	Understand testing that will characterize the performance characteristics of ATF designs.
Halden Program Meetings	Biannually	Understand testing that will characterize the performance characteristics of ATF designs. (In addition to a number of other non-ATF outcomes).
Severe Accident Analysis (MELCOR/MAAP)	TBD	Discuss severe accident modelling capabilities.
PRA	TBD	Discuss PRA modelling and licensing strategies.
ATF Fuel Fabrication Facilities Tour/Audit	As needed	Understand manufacturing processes and obtain information for developing licensing strategies.

INITIATING STAFF ACTIVITIES

Due to design-specific aspects and schedules, NRC activities are linked to the industry's progress and plans to utilize ATF. As such, it is necessary to have a mechanism for establishing commitments in advance of licensing activities. This plan provides estimated lead times for each activity associated with preparing the agency to conduct an effective and efficient licensing review of ATF applications. As the NRC gains more experience with these reviews, the lead times are expected to be adjusted to account for difficulties or efficiencies, as necessary.

These lead times dictate the amount of time ahead of licensing activities that data should be provided and formal communication of intent should be made. This mechanism is currently under development. Alternatively, the NRC could receive direction in the form of a budget allocation to initiate work on some or all of the preparatory activities laid out in this plan.

PREPARTORY ACTIVITIES

The preparatory activities have been grouped into four tasks. The highlights of each task and a summary of key information are provided in the activity tables below. Details of each task laid out in this plan have been documented separately and are referenced in each activity table. The tables identify the deliverables and schedules associated with that particular activity. A separate, non-public document also includes resource estimates for each activity that will be used to develop budgets. Assumptions used in the plan are identified along with open items requiring resolution for activities to proceed as planned. The staff will mitigate risks associated with this preparatory plan by staying closely engaged with external stakeholders and adjusting as circumstances warrant.

For the purpose of developing this plan, ATF concepts are broadly categorized as evolutionary or revolutionary. Evolutionary ATF concepts are those for which the agency's safety evaluation (SE) can largely rely on existing data, models, and methods. Coated Zirconium cladding and FeCrAl cladding fuel designs are examples of evolutionary ATF concepts. Revolutionary ATF concepts are those for which substantial new data, models, and methods need to be acquired and/or developed to support the agency's SE. U_3Si_2 fuel, metallic fuel, and SiC-based cladding are examples of revolutionary ATF concepts. Note that evolutionary and revolutionary are terms of convenience to indicate the differences in level of effort that needs to be expended by the NRC. Regulatory requirements do not vary between evolutionary and revolutionary designs.

Task 1: Regulatory Framework, In-reactor Performance

- Participation in industry-led phenomena identification and ranking table (PIRT) panels on in-reactor degradation mechanisms and failure modes under a wide array of accident conditions, performance-based metrics, and analytical criteria to ensure acceptable performance.
- Performance of a scoping study to (1) evaluate the applicability of existing regulations and guidance for each ATF design, (2) identify changes to or need for new regulations and guidance, and (3) identify any key policy issues.
- Determine/clarify the regulatory criteria that need to be satisfied for partial/full core use of ATF and regulatory options available to applicants and vendors.
- If needed, resolve policy issues and initiate rulemaking and guidance development activities.

Table 2. In-reactor Performance Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Mapping of hazards and failure mechanisms to general design criterion (GDC) b) Mapping of hazards and failure mechanisms to regulations c) Mapping of hazards and failure mechanisms to guidance documents d) Initiate rulemaking if necessary e) Initiate guidance development or revisions if necessary	
Lead NRC Organization	NRR/DSS/SNPB	
Triggers	a, b, c) budget allocation or letter of intent d) a or b indicated need for rulemaking e) c indicates need for new or revised guidance	
Lead Time	24 months – 48 months	36 months – 60 months
Final Product	a,b,c) hazards and failure mechanisms mapped to GDC, regulations, and guidance documents. d) new or revised rule e) new or revised guidance	
Reference document ML #	ML17325B773	

Task 2: Fuel Cycle, Transportation, and Storage Regulatory Framework

- Parts 70, 71 and 72 are largely performance based, therefore the staff does not anticipate identification of gaps in these regulations.
- Review guidance gaps may develop as the fuel cycle industry develops plans for manufacturing, transporting and storing ATF. Fuel cycle industry plans will be monitored and any needed regulatory guidance will be identified and developed in a timely manner.
- No fuel cycle licensing activities have been identified for evolutionary ATF concepts.

Table 3. Fuel Fabrication Licensing Activities

	Revolutionary ATF Concepts
Fuels Considered	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	License amendment for enrichment and/or fuel fabrication facility, if needed
Lead NRC Organization	NMSS/FCSE
Triggers	Application submittal
Lead Time	Depends on scope of application. Range from 6 to 18 months depending on the number, complexity of the review issues
Final Product	Possible supplemental review guidance. SE for modified or new license.
Reference Document ML #	ML17325B774

Table 4. Fuel Transportation and Storage Licensing Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	Modified or new Certificate of Compliance for Transportation Package(s) or Storage Cask	
Lead NRC Organization	NMSS/DSFM/RMB	
Triggers	Application submittal	
Lead Time	Depends on scope of application. Transportation package reviews range from 6 to 18 months depending on the number, complexity of the review issues.	
Final Product	SE and modified or new Certificate of Compliance.	Possible supplemental review guidance. SE and modified or new Certificate of Compliance.
Reference Document ML #	ML17325B774	

Task 3: Probabilistic Risk Analysis Activities

- The staff will evaluate how industry batch loading of ATF may affect the current risk informed programs like risk-informed technical specification (RITS) initiatives 4b and 5b
- The NRC's risk-informed oversight activities depend on standardized plan analysis risk (SPAR) models which will need to be updated to reflect batch loading of ATF

Table 5. PRA Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Participate in internal and external discussions and knowledge development related to ATF (e.g., internal working group meetings, public meetings) b) Complete licensing reviews, including potential TRs or industry guidance, related to the risk-informed aspects of ATF licensing	
	c) Complete a SPAR pilot of an evolutionary ATF design for a boiling water reactor (BWR) and pressurized water reactor (PWR) subject plant to assess core damage frequency (CDF)/large early release frequency (LERF) impact, gain risk insights, and identify potential improvements to guidance	c) Complete a SPAR pilot of a revolutionary ATF design for a BWR and PWR subject plant to assess CDF/LERF impact, gain risk insights, and identify potential improvements to guidance
	d) Update guidance (as necessary) to support licensing and oversight functions for plants making ATF-related modifications e) Update agency PRA models to reflect ATF-related changes to the as-built, as-operated plant for relevant plants/models	
Lead NRC Organization	NRR/DRA/APLB	
Triggers	TBD	
Lead Time	TBD	
Final Product	b) SE contributions for TRs and LARs related to ATF	
	c) Report documenting results and recommendations from evolutionary ATF SPAR pilot study	c) Report documenting results and recommendations from revolutionary ATF SPAR pilot study[1]
	d) Updated guidance (e.g., Risk Assessment Standardization Project guidance changes) to support licensing and oversight functions for plants making ATF-related modifications e) Updated agency PRA models to reflect ATF-related changes to the as-built, as-operated plant for relevant plants/models[2]	
Reference Document	ML17325B775	

[1] This task should be performed sequentially after the equivalent task for "evolutionary" ATF designs, so long as both "evolutionary" and "revolutionary" designs remain of regulatory interest.

[2] This would occur after approval of the associated licensing action.

Task 4: Analysis Capability Development

- Preparing the agency to conduct a meaningful and timely review of ATF includes developing a capability to analyze the performance of ATF under steady-state, design-basis accident (DBA) and beyond DBA conditions.
- Analysis capability development will be focused in the following areas: fuel performance, thermal hydraulics, neutronics, and source term and severe accident analysis.
- Development of NRC analytical capability for each area includes the following common tasks. Tables provided below include additional details, including triggers for each task. Reference material, cited in each table, elaborates on the nature of each task and estimates the duration of each task.
    - Code development needs will be evaluated with an initial *scoping study* to assess and identify information gaps.
    - Where necessary, code *architecture modifications* will need to be made (e.g., to remove Zr/UO_2 hard wired properties and assumptions or to solve the governing equations on a non-cylindrical geometry).
    - Where necessary, new *material properties* will be added and *new models,* which reflect new phenomena under steady-state, DBA, and beyond DBA conditions, will be developed. The duration of this task is intrinsically linked to the production and availability of data from on-going test programs, largely focused on separate effects.
    - *Integral assessments* of each of the updated codes, which includes verification and validation against data, will be completed and documented. The duration of this task is intrinsically linked to the production and availability of data from on-going test programs, largely focused on integral effects.
- Where possible, the NRC will collaborate with DOE in each of these activities to reduce duplication of effort in accordance with the DOE-NRC Memorandum of Understanding[1].
- Model development and integral assessment require distinct data sets. Reference material, cited in each table, discusses the data needs in each area. In accordance with major assumption one above the NRC will independently assess and analyze the data acquired by other entities.
- Estimated lead times to develop the codes to be able to analyze all currently proposed fuel/cladding types range from three to six years. The lead time includes all code development activities, and considers the time required to generate new data and new models for code development and integral assessment. The lead times vary by discipline and vary for evolutionary and revolutionary ATF designs. Generally, longer lead times are estimated for revolutionary designs with the expectation that new phenomenological models will need to be developed and validated. The lead times are not independent between various ATF designs because it is anticipated that code architecture updates made for the first design can be leveraged for other ATF designs.

[1] The 2017 ATF addendum on to the NRC-DOE MOU can be found the NRC Library, under “Document Collections” and “Memorandum of Understanding,” https://www.nrc.gov/reading-rm/doc-collections/memo-understanding/2017/

Table 6. Fuel Performance Analysis Development Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Scoping study b) Code architecture updates c) Material properties and models development d) Code assessment and validation	a) Scoping study b) Code architecture updates c) Material properties and models development d) Code assessment and validation
Lead NRC Organization	RES/DSA/FSCB	
Triggers	a) Budget allocation or formal communication of intent (format TBD) b) 18-36 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data	a) Budget allocation or formal communication of intent (format TBD) b) 24-36 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data
Lead Time	24-48 months	48-72 months
Final Product	a,b,c) Modified code c, d) Updated MatLib NUREG d) Updated Code Assessment NUREG	a,b,c) Modified code c, d) Updated MatLib NUREG d) Updated Code Assessment NUREG
Reference Document ML #	Analysis Capability Development Strategy – ML17325B776 Fuel Performance Strategy – ML17325B777	

Table 7. Thermal Hydraulics Analysis Development Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Scoping study b) Code architecture updates c) Material properties and models development d) Code assessment and validation	a) Scoping study b) Code architecture updates c) Material properties and models development d) Code assessment and validation
Lead NRC Organization	RES/DSA/CRAB	
Triggers	a) Budget allocation or formal communication of intent (format TBD) b) 12 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data	a) Budget allocation or formal communication of intent (format TBD) b) 24 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data
Lead Time	36 months	36 months
Final Product	a,b,c) Modified code d) Updated Code Assessment NUREG	a,b,c) Modified code d) Updated Code Assessment NUREG
Reference Document ML #	Analysis Capability Development Strategy – ML17325B776 Thermal Hydraulic Strategy – ML17325B778	

Table 8. Neutronics Analysis Development Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Scoping study b) Code architecture updates c) Neutronic properties and models development d) Code assessment and validation	a) Scoping study b) Code architecture updates c) Neutronic properties and models development d) Code assessment and validation
Lead NRC Organization	RES/DSA/FSCB	
Triggers	a) Budget allocation or formal communication of intent (format TBD) b) 12 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data	a) Budget allocation or formal communication of intent (format TBD) b) 24 months prior to expected receipt of data (pending outcome of scoping study) c,d)Receipt of data
Lead Time	24 months	36-48 months
Final Product	a,b,c) Modified code d) Updated Code Assessment NUREG	a,b,c) Modified code d) Updated Code Assessment NUREG
Reference document ML #	Analysis Capability Development Strategy – ML17325B776 Neutronics Strategy – ML17325B779	

Table 9. Source Term/Severe Accident Analysis Development Activities

	Evolutionary ATF concepts	Revolutionary ATF concepts
Fuels Considered	Cr-doped UO_2 Coated Zirconium cladding FeCrAl cladding	U_3Si_2 fuel SiC-based cladding Metallic fuel pellets or solid rods Any fuel >5% enriched uranium
Activity	a) Scoping study b) Infrastructure development c) Model development / implementation d) Model and integral assessment e) Source term evaluation analysis	a) Scoping study b) Infrastructure development c) Model development / implementation d) Model and integral assessment e) Source term evaluation analysis
Lead NRC Organization	RES/DSA/FSCB	
Triggers	c) Budget allocation or formal communication of intent (format TBD) b,c,d) Receipt of data	d) Budget allocation or formal communication of intent (format TBD) b,c,d) Receipt of data
Lead Time	24 months	48-72 months
Final Product	a,b,c) Modified code d) Updated Code Assessment e) NUREG Source Term Analysis Report	a,b,c) Modified code d) Updated Code Assessment e) NUREG Source Term Analysis Report
Reference document ML #	Analysis Capability Development Strategy – ML17325B776 Source Term/Severe Accident Analysis Strategy – ML17325B780	