Enhanced accident-tolerant fuel

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The Fukushima accident provided a strong reminder that the exothermic reaction between zirconium and steam, and the attendant hydrogen generation, can significantly affect the course of a severe accident. Part of the response to the accident was increased interest in the extent to which the fuel itself can mitigate the consequences of a severe accident. Improved fuel alone is not sufficient to provide the desired increase in reactor safety, but it can provide an important contribution.

With support from the US Department of Energy, AREVA has brought together a team that includes researchers (AREVA, Electric Power Research Institute, Savannah River National Laboratory, University of Florida, and University of Wisconsin), a fuel vendor (AREVA), and utilities (Duke Energy and Tennessee Valley Authority). The goal of the project is to develop new technologies that can be deployed in a lead assembly within ten years. The researchers have proposed a variety of approaches for improving the performance of the fuel, including new cladding and structural materials, fuel pellets with improved thermal characteristics, and coatings on the fuel rods. The expected performance of fuels that apply these technologies will be judged against the requirements of the vendor and utilities to determine those that are most promising for immediate development and those that may be suited for development in the future. The first review will consider the manufacturability of the proposed designs; the second will focus on performance. Materials that are suitable for immediate development will be considered for irradiation in a test reactor and subsequent use in lead assembly designs.

Enhanced Accident Tolerant Fuel (EATF)

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Technology advances can further enhance nuclear safety systems to address FUKUSHIMA type accidents in existing LWR design bases

EATF plays a part by improving margin

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EATF's role in enhancing margin

- **No technology will protect a reactor core in a complete loss of cooling scenario**
  - **Loss of the heat sink will result in the fuel temperature rise**
- **EATF should seek to delay or limit zirconium oxidation and damage to the fuel integrity during accident conditions**
- **Recognize that EATF must be economically competitive**
  - **Cannot divorce the fuel from the reactor**

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DOE Project Aim

- **Within 10 years deploy Lead Test Assemblies (LTAs) into an operational US light water reactor (LWR)**
  - **The nuclear industry is risk averse and so modifications to the fuel design will be incremental**
  - **The 10 year window and the risk adverse nature of the industry will limit the technologies that can be deployed**

- **Additional advances in EATF design after 10 year window should also be considered**

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Structure of a Fuel Assembly

- **In current LWR fuel design a large percentage of the Zr is used as the structural material supporting the rods**
  - **BWR ~ 30 %**
  - **PWR ~ 17 %**
- **Any technology that seeks to protect or replace the Zr must be capable of protecting the rods, grids and other structural components**

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Technology Considerations for EATF

- New clad and structural material
- Improved thermal characteristics of the pellets
- Coatings on the fuel assembly
- Combination of the above

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Industrial presence: Fuel

Richland, WA - US

- Fuel Manufacturing plant, Fuel Design

Fuel Manufacturing: 4 European sites

- Romans, Pierrelatte - France
- Lingen, Karlstein - Germany

Zirconium Manufacturing: 6 European sites

- Jarrie, Ugine, Rugles, Montreuil-Juigné, Paimboeuf - France
- Duisburg - Germany

Ulba -Kazakhstan

- Project of 1 JV* in Fuel Manufacturing: IFASTAR

* JV : Joint Venture

Other sites: 4

- Fuel Design, support functions: Lynchburg (Virginia) - US
- Fuel Design, european support functions, Lyon - France ; Erlangen - Germany
- Head office, Paris - France

China & Japan

- 2 JV* in Zirconium Manufacturing: CAST, ZP, Shangai - China / Shimonoseki - Japan
- 1 JV* in Fuel Manufacturing: MNF, Tokai - Japan

* JV : Joint Venture

16 industrial sites in Fuel activity: requiring optimization in the current context market

* JV : Joint Venture

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AREVA Team Members

- University of Wisconsin
  - 3 Enhanced Coatings
- University of Florida
  - SiC Fibers
  - Chromia doped fuel
  - Chromia Doped Fuel + SiC Fibers
- Savannah River National Laboratory
  - 3 Coatings
- Utility Partners
  - TVA and Duke to define user needs
  - EPRI to offer a Molybdenum Alloy for evaluation
- AREVA
  - Nano-particle coating on fuel rod
  - Chromia doped fuel assemblies in US reactor

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The AREVA team construct is balanced

Research

Technology

Fuel Vendor

Industrial

Utilities

Users

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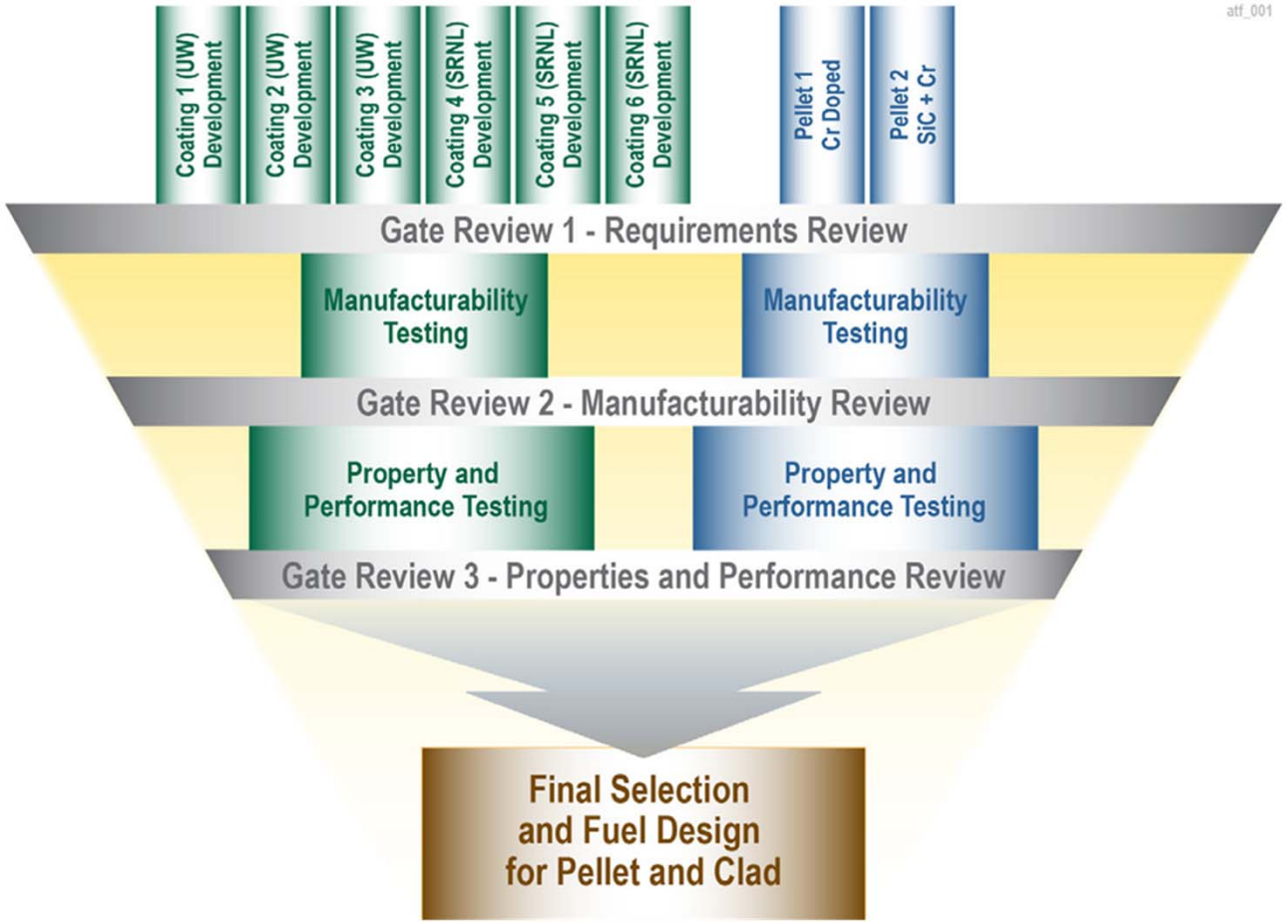
Development Process



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Wide range of technologies

- **Coatings**
  - SRNL developing “MAX Phase” materials and an enhanced surface treatment for zirconium. Example: Ti2AlC
  - UW developing direct deposit of metals and oxides on Zr clad using laser process
  - AREVA investigating use of nano-particles dispersed along a fuel rod intimately connected with the base normal crystalline zirconium alloy using various deposition techniques
- **Claddings**
  - EPRI investigating Molybdenum alloy materials to reduce clad reaction with steam in accidents
- **Pellets**
  - UF developing pellets with cromia dopants and SiC whiskers to improve thermal conductivity and fission gas retention. Spark plasma sintering process expected to reduce sintering costs

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Phased Approach

- **Phase 1: Discovery Phase** **2014**
  - Consider ideas and options promote innovation
  - Conduct gate review to help down select best available technology
  - Start irradiation tests in Advanced Test Reactor (ATR) of best options
- **Phase 2: Design Phase** **~2019**
  - Synthesize ATR results and finalize design
  - Develop licensing strategy to deploy LTAs to commercial reactor
- **Phase 3: Manufacture LTA's** **~2022**

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ATF in France

- AREVA involved in the evaluation of potential alternative nuclear fuel cladding materials
- Research conducted by CEA on enhanced safety margin materials
  - Steam oxidation resistant coatings on Zr-base cladding tubes
  - SiC-SiC claddings (Sandwich)
- Through bilateral contract, tripartite agreement (CEA-AREVA-EDF) or government funded project (ANR- MHYRACLE)
  - Presentation of Marion Le Flem (CEA)

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Conclusion

- **It is our responsibility to assure technological enhancements are applied to limit FUKUSHIMA type events**
  - **Industry stakeholders demand a critical review of available enhancements to nuclear safety**
- **EATF can play a role in these enhancements**
  - **Research should be conducted for incremental changes to LWR fuel that promote EATF characteristics**
  - **10 year window is embraced**
- **Cost for licensing, testing and fabrication of LTAs could be prohibitively expensive for any one vendor**
  - **Partnership with government and fuel vendors similar to the historical development of zirconium alloy clad**

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Thank you for your attention!

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