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PROtect: The leading Enhanced Accident Tolerant Fuel Program

Taking fuel to the next level by developing advanced fuel systems for nuclear reactors worldwide.

Your performance
is **our** everyday **commitment**

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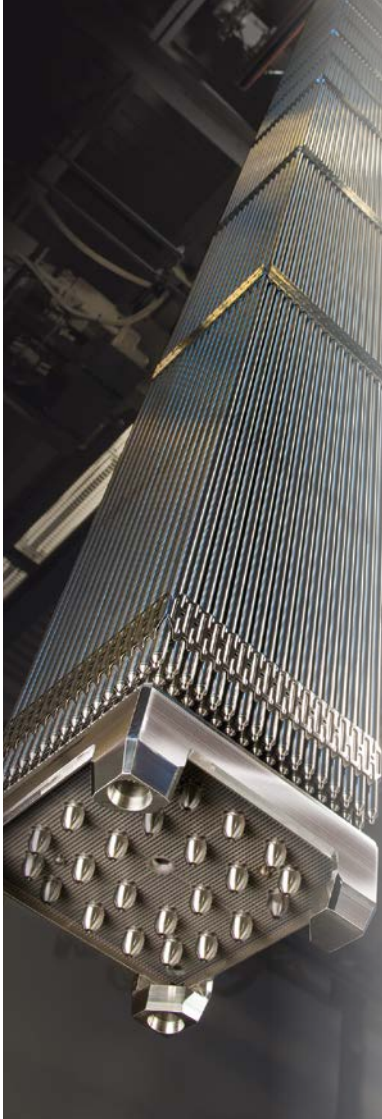
PROtect

PROtect is a cutting-edge research and development program using a global team of experts, focused on developing and implementing near-term and long-term solutions for advanced fuel systems for commercial nuclear reactors worldwide.

The Challenge

Framatome initiated its enhanced accident tolerant fuel program as a response to the Fukushima incident in 2011 to improve safety for nuclear plant operators.

Since then, we continue to develop technologies and solutions to make a more resilient nuclear power industry. As a result, we continually exceeded our targets and have implemented our solutions to reactors around the world.



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Utility Benefits

Today, the PROtect near-term solution provides beneficial margin gains concerning activity release in case of leaker, resistance to chipping of pellets, Design Basis Accident and coping time under severe accidents.

For the long-term solution a significant increase of margin is expected based on Silicon Carbide (SiC). The fuel economics will be targeted for improvement through increases in uranium utilization.

Near-term solution:
chromium-coated rods
+ chromia-doped fuel
pellets

Program Milestones

We developed an aggressive schedule to deploy the PROtect advanced fuel technologies to all Light Water Reactors of the current fleet, plus added flexibility for use in the next generation of advanced reactors.

Since 2016 material test rods have been under irradiation and are confirming the positive results from out-of-pile tests: chromium-coated M5**Framatome** cladding material test rods were successfully irradiated and operated in a commercial reactor in Europe for a complete five-year lifecycle.

In 2019 in-pile irradiation of the PROtect near-term solution began in a PWR in the U.S. with full length coated rods containing chromium-doped fuel pellets. This is the world-wide first complete full scale Enhanced Accident Tolerant Fuel (EATF) concept to be irradiated in a commercial reactor, quickly followed by an European and another American utility.

As of 2020 we established a fully qualified manufacturing capability for **chromia-doped fuel pellets and delivered the first batch reload** to a European PWR and to an American BWR.

In 2021, the **first worldwide complete PROtect EATF Cr-Cr assembly** was inserted for irradiation in a U.S. commercial reactor.

Near-Term Solutions

Our near-term solution is based on the close-to-market technologies chromium-coated fuel rods and chromia-doped fuel pellets.

Chromium-coated rods

Adding an optimized chromium coating to our existing M5**Framatome** cladding offers an advanced and mature cladding solution. The coating consists of a dense layer of chromium on the surface of the cladding tube (see Fig. 1).

We have a dense and adherent coating thanks to a proprietary Physical Vapor Deposition (PVD) process.

The chromium-coating improves wear resistance of cladding in contact with grids or debris.

Fig. 1: Metallographic cross-section of chromium-coated M5**Framatome** cladding tube, before irradiation, showing excellent adherence of the two materials.

› Chromium-coated cladding contributes significant safety margin gain

This solution shows greatly improved high-temperature steam oxidation resistance with reduced cladding creep and ballooning.

PROtect chromium-coating technology is optimized regarding the cladding behavior. The development of this technology was initiated by the French Alternative Energies and Atomic Energy Commission (CEA) and is supported by its French partners Framatome and EDF in the frame of the French Three Partite Institute in addition to the U.S. Department of Energy.

Chromia-doped fuel

We have in-pile experience of chromia-doped fuel pellets since 1997 with a burn up of up to 75 MWd / kgU. These chromia-doped fuel pellets are similar to standard UO_2 pellets, but have higher density, a larger grain size and improved viscoplasticity.

Larger grain size improves the retention of fission gas under transient conditions and in the event of failed fuel rods doped pellets have shown better resistance to pellet-to-cladding interaction.

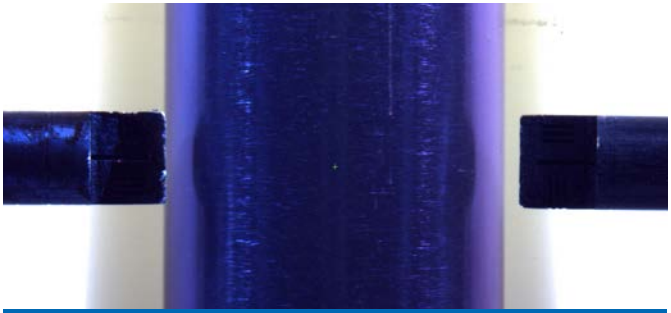

Fig. 2: Chromium-Coated cladding showing excellent performance after 5 cycles of irradiation.

› PROtect improves fuel cycle economics during normal operation.

Long-Term Solutions

The long-term solutions focus on technologies which will offer more margin gain under Beyond Design Basis Accidents but have substantial development efforts remaining with deployment targeted for mid-2030s. Primarily we are developing silicon carbide-based cladding solution with the following objectives:

- Very low oxidation kinetics under high-temperature steam in lightwater reactor conditions
- High strength at high temperatures
- High melting temperature

The full value of SiC-based cladding will be realized through the performance attributes listed above.

Additionally, building on the promise of SiC material, we are exploring BWR applications by replacing zirconium fuel channels. This could represent a 40% reduction of zirconium in the core and thus, could significantly reduce the amount of hydrogen being produced in a postulated event.

Fuel Assembly Structure

The PROtect features will extend the benefits of our existing and proven cladding.

Especially for the near-term solution, licensing requirements will be minimized. M5**Framatome** and Q12-based structures are suited for the near-term solution of PROtect fuel.

Codes & Methods

Our current Codes and Methods are suited for chromia-doped fuel pellets in reloads and chromium-coating in lead fuel assemblies worldwide.

Chromia-doped fuel BWR topical report was approved by the U.S. Nuclear Regulatory Commission (NRC). Extension to PWR is under review by the NRC.

PROtect timeline

2025

First PROtect program reloads capabilities.

2021

First complete PROtect fuel assembly with chromium-coated fuel rods and chromia-enhanced pellets put into operation in a U.S PWR reactor.

GAIA PROtect full length fuel rods completed their first cycle in two U.S. and one European PWR demonstrating excellent performance results and operated as expected.

PROtect fuel segments completed their first 5-year lifecycle in a Swiss PWR and demonstrating excellent performance and visual results.

Manufacturing of SiC rodlets (including coating as anti-recession solution and brazing for closure of the rodlet) for irradiation in a test reactor.

2019

First in-pile irradiation of the near-term solution of the PROtect program started in commercial PWRs in Europe (HTP Design) and in the U.S. (GAIA and HTP Design).

2018

Fully qualified process for manufacturing of near-term solution.

2016

First irradiation of chromium-coated and SiC-SiC material test rods.

1997

First irradiation of chromia-doped fuel pellets in a commercial reactor.

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Framatome is an international leader in nuclear energy recognized for its innovative solutions and value added technologies for the global nuclear fleet.

With worldwide expertise and a proven track record for reliability and performance, the company designs, services and installs components, fuel, and instrumentation and control systems for nuclear power plants.

Its more than 14,000 employees worldwide, work every day to help Framatome's customers supply ever cleaner, safer and more economical low-carbon energy.

Framatome is owned by the EDF Group (75.5%), Mitsubishi Heavy Industries (MHI – 19.5%) and Assystem (5%).

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Reference Data Sheet Number: B-G-A519-ENG-092021
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