Track Record of the AREVA NP Nuclear Fuel in the United States of America

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Abstract

 Having its American, German and French legacy, AREVA NP has been and is supplying nuclear fuel assemblies and associated core components to PWR and BWR reactors around the world. To develop its action on the world market, AREVA NP has organized its activities on its major locations in Europe (France, Germany & Belgium) and in the USA. Also AREVA NP is strongly represented in the other nuclear countries (Asia, Eastern Europe, South America, South Africa and remaining European countries).

Today AREVA NP has supplied more than 110,000 PWR and 51,000 BWR fuel assemblies to the world market. In the USA, AREVA NP has produced about 28,000 PWR fuel assemblies. Representing almost a quarter of the PWR American fuel market, AREVA NP is currently supplying or starting to supply 22 reactors from its 2 manufacturing plants located at Lynchburg (VA) and Richland (WA). This supply is currently based on HTP and Mark-BW designs, which have been distributed to all types of the US reactors and satisfy the NRC requirements. Also they are prepared for the current development of reactors, including AREVA NP’s EPR reactor.

At the time being our US PWR fuel takes the advantage of the thorough review performed on all our products, in order to keep the most proven and best performance features and allow us to better respond to each customer need. We propose the AGORA products with enough flexibility and variants to offer customized products, well suited to each customer’s needs. These products incorporate a set of common characteristics and associated features, which are:

- the use of the M5® alloy, as cladding material and as structural material,
- a welded structure comprising the HMP alloy 718 bottom end grid, the MONOBLOC guide thimbles and the ROBUST FUELGUARD as lower tie plate.

AREVA NP’s fuel activities are supported by their engineering, manufacturing and fuel services which enable AREVA NP to provide utilities with licensed fuel design, a
complete fuel package and suitable supports for the fuel delivery and fuel post-irradiation examinations.

Looking to the future, AREVA NP’s next generation of fuel is under development, in response to the perceived needs of its customers and identification of their technical objectives.

The purpose of this paper is to present the AREVA NP fuel consistent activities in the USA, which constitute an advantage for other market applications, especially in the Pacific Basin.

**Paper**

1. **Introduction**

As a leading U.S. nuclear supplier, a key player in the electricity and distribution sector and based on its 8,000 American employees, AREVA is committed to be a major actor on the electricity market and thus has the best grounding for overseas development. AREVA combines homegrown leadership, access to worldwide expertise and a proven track record of performance through the U.S.A.

AREVA NP combines its best existing capabilities in U.S. to develop its activity for nuclear fuel production. During the past years following the merger of Framatome and Siemens nuclear activities, AREVA NP took advantage of the great value gained from respective past experiences, working together to make the best out of them and thus being able to better fit customer needs and expectations. Its objective has been to streamline the human and technical resources, in order to keep the most proven and best-performance features and allow us to better respond to each customer need.

Today, AREVA NP proposes AGORA fuel products, with enough flexibility and variants to offer customized products, well suited to each customer’s needs. To develop these products for the U.S nuclear power plants, AREVA NP is supported by its 2 plants of engineering & manufacturing, which develop the AGORA products and prepare the future by participating in GAIA, the Project of next generation of products.

2. **AREVA NP’s Fuel History**

The proven nature of AREVA NP’s fuel assemblies for PWR is established through the accumulated experience and associated reliability of our products. Their excellent in-reactor experience is the result of making the right design choices for components and materials.

Since 1996 the products of the AFA series have been introduced in more than 50% of the 17x17 PWR reactors in Europe (France, Belgium, Germany, Sweden, Spain), in Asia and
in South-Africa. More than 12,000 fuel assemblies have been irradiated, with a maximum burn-up reached to 58 GWd/t.

The first HTP fuel assemblies were inserted into two U.S. plants in 1988 and into a German plant in 1989. More than 6,000 HTP fuel assemblies have been loaded into 39 plants in Europe (Belgium, France, Germany, Sweden, Switzerland, and UK), in the U.S. and in Asia. The fuel assembly burn-up reached is up to 57 GWd/t.

The Mark-BW fuel assembly was first introduced in the U.S. in 1987 and more than 3,000 fuel assemblies have operated. Several U.S. utilities operating different reactors have chosen this fuel assembly best suited for their specific needs. This design has successfully achieved a fuel assembly burn up level of 67.6 GWd/t.

3. US Manufacturing Capabilities

Lynchburg Plant
The Lynchburg fuel manufacturing facility (U.S.A.), on the East Coast, produces fuel assemblies for pressurized water reactors (PWR). The plant is licensed for fuel assembly production of up to 5.0 wt% $^{235}$U. Burnable poison rod assemblies, in-core detectors, axial power shaping rods, specialty components and $\text{B}_4\text{C}$ pellets are also produced in this plant. Adjacent to the fuel manufacturing facility are two facilities dedicated to fuel activities developing.

Production Operations
- Rod fabrication (UO2)
- Core Component assemblies (Thimble Plug, RCCA & CEA)
- Bundle assembly
- PWR control components
- In-core detector assemblies
- Burnable pellets, rods, and assemblies

Infrastructure
- Quality control system
- Training center
Fuel inspection and repair services
Shipping and logistics

Richland Plant
The Richland fuel manufacturing plant (U.S.A.), located on the West Coast, produces UO2 powder, pellets and fuel rod components in addition to fuel assemblies for both pressurized water reactors (PWR) and boiling water reactors (BWR). The plant is licensed for fuel assembly production of up to 5.0 wt% $^{235}\text{U}$ and has conversion and pelletizing capacities.

Fuel Production Operations
- UF6/UO2 conversion
- Pelletizing (UO2 + Gd2O3/UO2)
- Rod fabrication (UO2 + Gd2O3/UO2)
- Component fabrication
- Bundle assembly
- Clean fuel scrap recovery

Infrastructure
- Quality control system
- Analytical and materials laboratories
- Low-level waste cleanup and incineration
- Advanced fuel design performance testing
- Shipping and logistics

4. Overview of our U.S. PWR Fuel Designs
Regarding PWR fuel assemblies on the U.S. market, AREVA NP has a portfolio with different products having each their specific design, history and performance.

The hereafter components are the cornerstones of the upgraded AGORA fuel assemblies that AREVA NP proposes in order to provide performance required by all reactors:

- fuel rods, guide tubes and grids in M5® alloy,
- welded structures comprising the HMP grid as end spacer, the MONOBLOC guide tube and the ROBUST FUELGUARD as lower tie plate.

The choice of the mixing spacer and some other options in the structure design leads to a well tailored fuel assembly, responding in the most appropriate way to specific reactor operation, fuel management and licensing requirements.

The family of components is based on the best characteristics and associated features, which are the:
**M5® material**

M5® was developed from a very large R&D program including the evaluation of several candidates. It offers high reliability within a wide range of normal and hypothetical accident operating conditions, dimensional stability, high corrosion resistance and low hydrogen pickup, improved PCI behavior and compliance with RIA and LOCA criteria. To date more than 900,000 M5® rods have been irradiated, with a maximum burn up reached of 80 GWd/t.

**ROBUST FUELGUARD lower tie plate**

Fuel rod failures induced by debris have been almost completely eliminated with the introduction of the anti-debris devices in the early 1990s. The debris-resistant ROBUST FUELGUARD lower tie plate offers high protection against debris-induced fretting failures. Moreover, the ROBUST FUELGUARD parallel curved blades reduce the orifice jets and the associated turbulence from the lower core plate.
**MONOBLOC guide tubes**

With the MONOBLOC guide tube, an effective and innovative solution has been designed to reinforce the fuel assembly lateral stiffness. The patented one piece MONOBLOC guide tube consists of an enlarged, thicker and more stable tube including the dash-pot area.

**HMP end spacer**

The design of the HMP spacer is based on the design of the Zirconium alloy HTP fuel spacer. It benefits from the robustness of the HTP design. It has to be emphasized that grid-to-rod fretting has never been observed in an HMP spacer.

Inconel was selected as material for the spacer strips due to its increased strength and resistance to relaxation. Thereby it was also possible to slightly reduce the strip thickness. The HMP spacer is equipped with straight flow channels in order to obtain a low pressure loss. Due to the different spacer and guide tube materials, the HMP spacer is axially connected to the guide tubes by means of sleeves or capture rings.

**Mixing spacers**

The mixing spacer is the most sensitive component of the fuel assembly. So as to better fit some customer needs for high CHF performance, AREVA NP especially offers the Mark-BW mixing spacer design in the AGORA M fuel assembly.

**Mark-BW mixing spacer**

The Mark-BW mixing spacer design is based on a monometallic spacer, widely used in the U.S. The Mark-BW fuel assembly design is notorious for its excellent licensed thermal performance, which is derived predominantly from the optimized mixing vane design and optional mid-span mixing grids for additional thermal performance. Fuel rod support is maintained by a combination of hard-stops and soft-stops or spring elements integrated into the strip designs. The wide rod support contact surfaces contribute to the excellent fretting resistance.
5. The AGORA M Fuel Assembly

The AGORA M fuel assembly features a set of common characteristics and associated features developed for the AREVA NP’s nuclear fuel family. It presents the following design advantages:

- mixing spacers available from the Mark-BW design, to provide the maximum thermal margin and compatibility with resident fuel,
- margin for overall handling and rod cluster control assembly (RCCA) insertion due to the MONOBLOC,
- industry-leading debris protection through our innovative ROBUST FUELGUARD bottom nozzle,
- taking advantage of the robustness of the HMP end spacer,
- margin for high burn-up performance with the M5® for cladding and structure material.

6. The AGORA H Fuel Assembly

Highlights of the AGORA H fuel assembly are described below:

- the ultimate in terms of fixing the fuel rod in the spacer is realized with the HMP Inconel end grid,
- special type of HTP spacer with integrated flow mixing channels which enhance coolant mixing while maintaining a low flow resistance,
- debris protection for the fuel rods is provided by the ROBUST FUELGUARD bottom end piece,
- margin for overall handling and rod cluster control assembly (RCCA) insertion due to the MONOBLOC,
- achievement of high burn-up due to M5® cladding and structure material.
7. U.S. Fuel Experiences

Mark-BW Experience
A total of over 3,000 fuel assemblies based on Mark-BW design have operated in nine Westinghouse 17x17 plants with a high reliability.

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<thead>
<tr>
<th>Reactor</th>
<th>Delivered Fuel Assemblies</th>
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<tbody>
<tr>
<td>1-</td>
<td>524</td>
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<td>48</td>
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<td><strong>TOTAL</strong></td>
<td><strong>3,089</strong></td>
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In addition AREVA NP in 2005 got a supply order of 17 firm fuel batches and 31 optional batches from 4 U.S. nuclear power plants.

The Mark-BW fuel assembly has been employed in the U.S. with an excellent performance track record. Today the AGORA M combines this unparalleled thermal performance with the legacy of a beyond-reproach fuel performance history.

HTP Experience
The proven experience of the HTP design in ten U.S. reactors is as follows:

<table>
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<th>Reactor</th>
<th>Delivered Fuel Assemblies</th>
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<tbody>
<tr>
<td>1-</td>
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<td>2-</td>
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<td>10</td>
<td>76</td>
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<td><strong>TOTAL</strong></td>
<td><strong>2605</strong></td>
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</table>
The HTP fuel has been proven to combine the best mechanical behavior with high resistance to the grid-to-rod fretting failure mechanism. Employing the HTP grid design for the B&W plant is one example of the benefits seen in combining the Siemens and Framatome-ANP companies’ experiences. Today the AGORA H fuel assembly highlights this excellent fuel performance.

8. Fuel for the Future

The new PWR Project called GAIA embodies the common development effort undertaken by the AREVA NP Fuel Sector for the new fuel assembly generation. This future product will be designed to meet the market needs and customers expectations at that time and will take into account the foreseeable developments in technical and licensing requirements.

Our multiregional team is tasked to run this cross-business project by promoting the integration and development of a joint technology. The current technical direction of the Project is originated in the customer expectations and is conducted by:

- The competitiveness and the reliability of the fuel assembly which constitute the major objectives. To operate the reactor with a very high-performance fuel up to highest burn-up, a high level of quality, no defect during irradiation, high level of availability factor constitute a permanent challenge in the development of a new fuel product. The aspects related to the prolongation of reactor lifetime will be also included in this prospect,
- Manufacturing improvement and particularly the process optimization which constitute a permanent objective,
- The reduction of global costs which becomes an essential factor. It will not have to consider only the cost of fuel cycle but also the total operating costs attributable to fuel, including the aspects related to the shortening of outages and getting the most out of fuel flexibility,
- The transport aspect and fuel situation at end of life which are taken into account as from design,
- Specific needs which are identified such as remedies against Pellet-Clad Interaction (PCI) and Abnormal Axial Offset (AOA).

Creativity sessions with targeted technical focuses, bringing together French, German and American staff, were performed in order to generate innovative ideas which entered into development.

The conceptual phase has been performed to work out the most promising concepts and conduct various tests so to get a clear idea on feasibility and assess intrinsic performance. The final design phase will allow the refinement of the adopted concepts and the necessary licensing work.