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Original Article

Mechanical robustness of AREVA NP's GAIA fuel design under seismic and LOCA excitations

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ABSTRACT

Recent events in the nuclear industry have resulted in a movement towards increased seismic and LOCA excitations and requirements that challenge current fuel designs. AREVA NP's GAIA fuel design introduces unique and robust characteristics to resist the effects of seismic and LOCA excitations.

For demanding seismic and LOCA scenarios, fuel assembly spacer grids can undergo plastic deformations. These plastic deformations must not prohibit the complete insertion of the control rod assemblies and the cooling of the fuel rods after the accident. The specific structure of the GAIA spacer grid produces a unique and stable compressive deformation mode which maintains the regular array of the fuel rods and guide tubes. The stability of the spacer grid allows it to absorb a significant amount of energy without a loss of load-carrying capacity.

The GAIA-specific grid behavior is in contrast to the typical spacer grid, which is characterized by a buckling instability. The increased mechanical robustness of the GAIA spacer grid is advantageous in meeting the increased seismic and LOCA loadings and the associated safety requirements. The unique GAIA spacer grid behavior will be incorporated into AREVA NP's licensed methodologies to take full benefit of the increased mechanical robustness.

1. Introduction

Recent events in the nuclear industry have resulted in a move toward increased seismic and LOCA excitations and requirements. Reevaluation of the seismic risk at nuclear power plants has been requested by various safety authorities with the goal of evaluating a plant's resistance to design basis and beyond design-basis accidents. The increased excitations present a challenge to current fuel designs to maintain sufficient margins to spacer grid crushing as well as component stresses. For demanding seismic and LOCA scenarios, the assembly spacer grids can undergo plastic deformation if the impact forces exceed the strength of the spacer grid. These grid deformations must not prohibit the complete insertion of the control rods and the cooling of the fuel rods after the accident. AREVA NP's GAIA fuel assembly and, specifically, the GAIA spacer grid have the potential to meet the demands of the increased seismic and LOCA requirements.

2. GAIA fuel assembly design

AREVA NP's new GAIA fuel assembly design for pressurized water reactors (PWR) has been in operation as lead fuel assemblies in Europe since 2012 [1] and in the United States since 2015. The GAIA fuel assembly has been designed to maximize the product performance in the following domains:

- rod-to-grid fretting resistance, thanks to use of 8 soft line contacts per cell and a low fluid-structure interaction obtained via streamlined components like the GRIP bottom nozzle;
- critical heat flux with optimized mixing features on grids and optional intermediate mixers;
- and fuel assembly bow resistance, thanks to the use of reinforced guide tubes made with the Q12[i] creep resistance alloy, each welded in 8 points to the spacer grids.

The GAIA assembly also introduces a new robustness to resist the effects of seismic and LOCA excitations by means of the GAIA spacer grid. The GAIA spacer grid design is distinguished by the fuel rod support spring hulls which are inserted and welded at the strip

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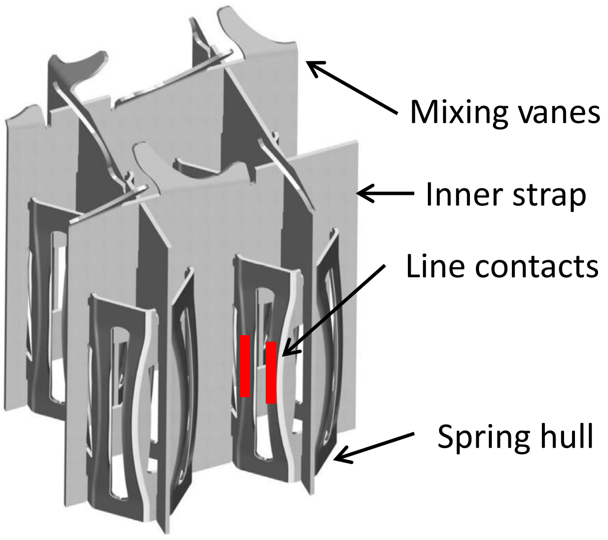


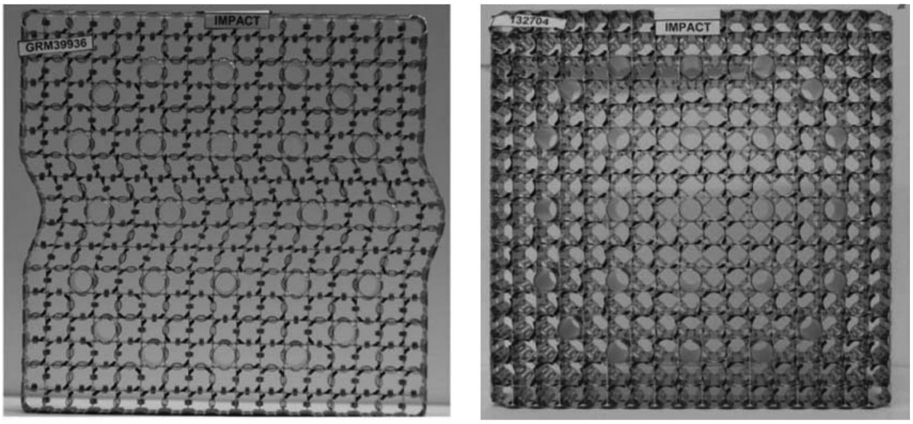
Fig. 1. Detail of the GAIA spacer grid rod support and spring hull.

intersection (see Fig. 1). The inclusion of the spring hull provides a resistance to the localized buckling and bending of the grid strips at the intersections, which is the typical failure mode of the classical spacer grid.

2.1. Spacer grid behavior in compression

The specific structure of the GAIA spacer grid produces a unique and stable compressive deformation mode. The compressive deformation is distributed uniformly over the entire grid, thus maintaining the regular array of the fuel rods and guide tubes. By contrast, the classical spacer grid exhibits a pronounced shearing deformation in the postbuckling state which distorts the fuel rod and guide tube array. A comparison of the compressive deformation modes for the classical spacer grid and the GAIA spacer grid is provided in Fig. 2. Both spacer grids have experienced approximately 2 mm of permanent deformation in the loading direction.

The stability of the GAIA spacer grid under compressive loads allows it to absorb a significant amount of energy without a loss of load-carrying capacity. The response of the GAIA spacer grid to dynamic impacts of increasing kinetic energy is plotted in Fig. 3 for beginning-of-life (BOL) conditions and in Fig. 4 for simulated end-of-life (EOL) conditions. The response of the classical spacer



(A) (B)

Fig. 2. Comparison of failure modes. (A) Classical spacer grid. (B) GAIA spacer grid.

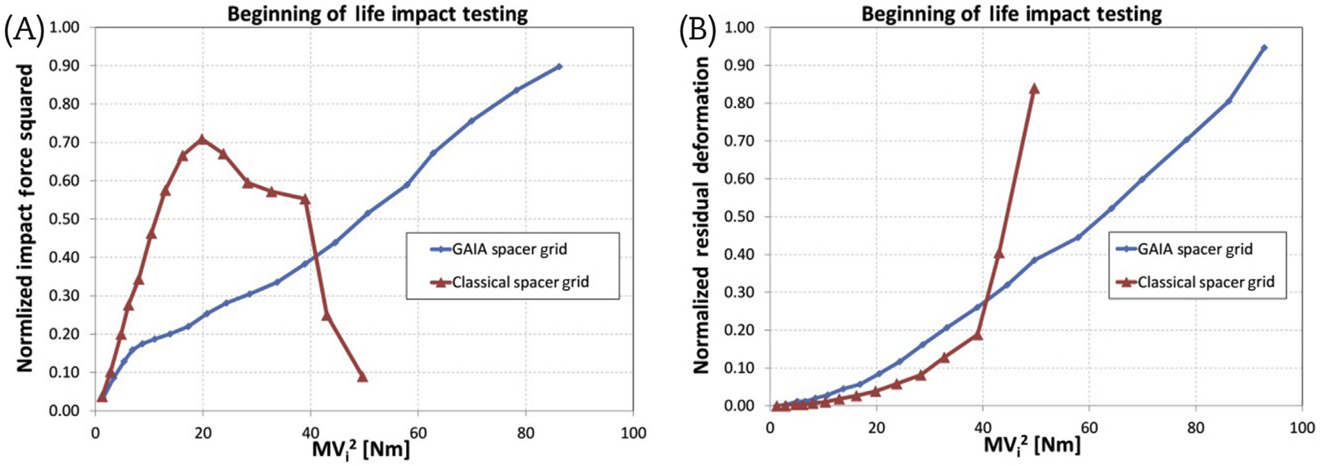


Fig. 3. Beginning-of-life conditions. (A) Impact force squared. (B) Residual deformation versus impacting kinetic energy.