framatome

GAIA Fuel Assembly Mechanical Design

ANP-10342NP-A
Revision 0

Topical Report

September 2019

Framatome Inc.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 24, 2019

Mr. Gary Peters, Director
Licensing and Regulatory Affairs
Framatome Inc.
3315 Old Forest Road
Lynchburg, VA 24501

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME INC. TOPICAL REPORT ANP-10342P, REVISION 0, "GAIA FUEL ASSEMBLY MECHANICAL DESIGN" (CAC NO. MF9078/EPID: L-2016-TOP-0016)

Dear Mr. Peters:

By letter dated December 21, 2016 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16362A278), Framatome, Inc. (Framatome, formerly AREVA, Inc.) submitted Topical Report (TR) ANP-10342P, Revision 0, "GAIA Fuel Assembly Mechanical Design," to the U.S. Nuclear Regulatory Commission (NRC) staff for review and approval. By letter dated June 25, 2018 (ADAMS Accession No. ML18138A357), an NRC draft safety evaluation (SE) regarding our approval of TR ANP-10342P, Revision 0, was provided for your review and comment. By letter dated December 20, 2018 (ADAMS Accession No. ML18360A171), Framatome provided comments on the draft SE. The NRC staff's disposition of the Framatome comments on the draft SE are discussed in the attachment (ADAMS Accession No. ML19204A055) to the final SE enclosed with this letter.

The NRC staff has found that TR ANP-10342P, Revision 0, is acceptable for referencing in licensing applications for nuclear power plants to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in licensing action requests, our review will ensure that the material presented applies to the specific plant involved. Requests for licensing actions that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Framatome publish approved proprietary and non-proprietary versions of TR ANP-10342P, Revision 0, within 3 months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The approved versions shall include an "-A" (designating approved) following the TR identification symbol.

As an alternative to including the RAIs and RAI responses behind the title page, if changes to the TR were provided to the NRC staff to support the resolution of RAI responses, and if the NRC staff reviewed and approved those changes as described in the RAI responses, there are two ways that the accepted version can capture the RAIs:

1. The RAIs and RAI responses can be included as an Appendix to the accepted version.
2. The RAIs and RAI responses can be captured in the form of a table (inserted after the final SE) which summarizes the changes as shown in the approved version of the TR. The table should reference the specific RAIs and RAI responses which resulted in any changes, as shown in the accepted version of the TR.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Framatome will be expected to revise the TR appropriately or justify its continued applicability for subsequent referencing. Licensees referencing this TR would be expected to justify its continued applicability or evaluate their plant using the revised TR.

Sincerely,

Dennis C. Morey, Chief
Licensing Processes Branch
Division of Licensing Projects
Office of Nuclear Reactor Regulation

Project No. 728
Docket No. 99902041

Enclosure:
Final Safety Evaluation

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT ANP-10342P, REVISION 0,

"GAIA FUEL ASSEMBLY MECHANICAL DESIGN"

FRAMATOME INC.

PROJECT NO. 728/DOCKET NO. 99902041

1.0 INTRODUCTION

By letter dated December 21, 2016 (Reference 15), Framatome Inc. (Framatome, formerly AREVA Inc.) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) ANP-10342P, "GAIA Fuel Assembly Mechanical Design." Approval would permit licensees with Westinghouse Electric Company (Westinghouse or W) three-loop and four-loop nuclear power reactors that use a 17 x 17 fuel rod array to reference the generic TR for use of the GAIA fuel. The GAIA design is a conglomerate of the previous Framatome, Babcock and Wilcox Company (B&W), and Electricité de France (EdF) fuel designs with some additional new design features and optimizations focused on thermal efficiency. This TR evaluated the performance of the GAIA fuel design against the design criteria defined in the Standard Review Plan (SRP), Section 4.2, "Fuel System Design" (Reference 1).

Per letter request (Reference 19), Section 9.0 of the TR, has been withdrawn from consideration. This leaves the update process for GAIA to only that which is allowed per 10 CFR 50.59 and other existing regulations. Specifically, the EMF-92-116(P)(A) TR (Reference 8) is not applicable to GAIA. The NRC staff approves the use of this TR subject to the limitations and conditions (L&Cs) listed in Section 4.0 of this safety evaluation (SE).

The SE considers comments and additional information provided in References 17,18, and 19. Throughout this document the term GAIA is meant to mean the GAIA-W17x17-264 rods fuel assembly (FA).

2.0 REGULATORY EVALUATION

Fuel designs must ensure that the reactor core will have the appropriate margin to assure that the specified acceptable fuel design limits (SAFDLs) criteria in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, General Design Criterion (GDC) 10, "Reactor Design," are met. Additionally, GDC 27, "Combined Reactivity Control System Capability," and GDC 35, "Emergency Core Cooling," require that licensees maintain control rod insertability and core coolability. Loss-of-coolant accident (LOCA) coolability requirements are contained in 10 CFR 50.46. The NRC staff review guidance for new fuel designs is contained in SRP Section 4.2.

The guidance provided within the SRP forms the basis of the NRC staff's review and ensures that the criteria of 10 CFR 50.46, GDCs 10, 27, and 35 are met.

For many of the SRP 4.2 criteria, Framatome does not address the acceptance criteria within this TR. For completeness, this SE acknowledges that those evaluations are done elsewhere and, if necessary, imposes any needed restrictions required for the safe operation of the GAIA FA where those outside analyses may be out-of-date to the current state of knowledge, requirements, or industry issues that need to be addressed.

3.0 TECHNICAL EVALUATION

The GAIA design is a conglomerate of the previous Framatome, B&W, and EdF fuel designs with some additional new design features and optimizations focused on thermal efficiency including:

- GRIP™ bottom nozzle based upon proven FUELGAURD™ and TRAPPER™ bottom nozzles,
- GAIA end and intermediate spacer grid based upon proven HMP™ and HTP™ spacer grid designs (respectively),
- Intermediate GAIA Mixer grid based upon Advanced Mark-BW design,
- Standard Reconstitutable Top Nozzle,
- Framatome standard M5® material for the cladding,
- Q12™ material for MONOBLOC™ guide tubes (GT) and instrument tubes (IT) [NEW FEATURE]
- Framatome standard M5® material for both intermediate grid designs and Alloy 718 for the end grids.

Per letter request (Reference 19), Section 9.0 of the TR, has been withdrawn from consideration. This leaves the update process for GAIA to only that which is allowed per 10 CFR 50.59 and other existing regulations. Specifically, the EMF-92-116(P)(A) TR (Reference 8) is not applicable to GAIA.

The objectives of this fuel system safety review, as described in SRP Section 4.2, are to provide assurance that (1) the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs), (2) fuel system damage is never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for postulated accidents, and (4) coolability is always maintained. A fuel system is "not damaged" when fuel rods do not fail, fuel system dimensions remain within operational tolerances, and functional capabilities are not reduced below those assumed in the safety analyses. Fuel rod failure means that the fuel rod leaks and that the first fission product barrier (the cladding) has been breached. Coolability, which is sometimes termed coolable geometry, means that the fuel assembly retains its rod-bundle geometrical configuration with adequate coolant channels to permit removal of residual heat even after an accident.

3.1 Fuel Assembly Design

The GAIA fuel assembly design is intended for use in Westinghouse three-loop and four-loop reactors which use a 17 x 17 fuel rod array, with each assembly containing 264 fuel rods. This SE documents the NRC staff basis for approving this specific design and application. If Framatome wants to develop and market a comparable GAIA product for any other design or application, it must be submitted for review. This is consistent with past practice.

Other fuel assembly designs, not discussed in ANP-10342 or considered in the NRC staff review, include the following:

- W15x15-204 rods
- W14x14-179 rods
- Combustion Engineering (CE) 16x16-236 rods
- CE14x14-176 rods
- Palisades-216 rods
- B&W15x15-208 rods

The GAIA fuel assembly design is a conglomerate of the previous Framatome, B&W, and EdF fuel designs with some additional new design features focused on thermal efficiency. The design uses the M5® advanced alloy which has been previously approved (References 3 and 9) for cladding. Q12™ alloy (Reference 5) is used for GT and IT that is one of the first deployments of this new approved alloy. A thorough description and schematic diagrams of the fuel assembly, fuel rod, grids, top nozzle, guide tubes and instrumentation tubing, bottom nozzle, and the materials used for each component are provided in Section 4.0 of the TR. Based on the content of the TR, the staff concludes that a satisfactory description of the fuel assembly has been provided for this review.

3.2 Lead Test Assembly (LTA) Program/Operating Experience (OPX)

The LTA program for confirming the irradiation behavior of the GAIA fuel assembly design used LTAs in locations where the LTAs saw near-peak core power conditions. The GAIA program was a global design effort within Framatome's three main regions of operation (U.S., France, and Germany), in cooperation with two customers to thoroughly test the design prior to batch implementation. Four GAIA LTAs were inserted in the core of an international reactor in 2012. Eight GAIA LTA's were inserted in the core of a U.S. reactor in 2015. Both plants are Westinghouse 3-loop designs.

At the time of the TR submittal, the U.S. based LTAs only had one cycle of operation. During their core residency, two cycles are expected to be in high duty locations and during the third cycle, some the LTAs are to be placed on the core-periphery, a hostile hydraulic environment. Post-irradiation examinations (PIEs) were and will be performed after every irradiation cycle to confirm that the LTAs were operating as predicted. The PIEs that have and will be performed were appropriate for confirming the performance of the fuel design and the results met expectations. Therefore, the LTA performance is acceptable but is subject to L&C #3 to ensure sufficient high burnup fuel rods have been examined prior to a full batch of GAIA fuel assemblies have reached end-of-life (EOL).

Most of the components on the GAIA FA are evolutions in design from previous components in many different FA designs. As such, a smaller LTA program is warrented based on the large OPX database composed of the earlier variants of those components. The exception to this is the Q12™ material used for the GAIA GTs, but that marterial was approved outside this TR (Reference 5). The table below summarizes both the OPX of the previous variants of the components and LTA for the new components. Some values in the table are estimates/approximations (Est.).

Component	**No. of Reactors**	**No. of FA**	**No. of Component s/Rods**	**Region United States (U) International (I)**	**Type LTA/OPX**	**Year Introduced**
GAIA LTA	1	4	-	1 I	LTA	2012
GAIA LTA	1	8	-	1 U	LTA	2015
M5™ Fuel Rods	84	21000	5000000	U, I (various)	OPX	1995 U
GAIA M5™ Fuel Rods	2	12	3180	1 U 1 I	LTA	2012
HTP™ Spacer Grid	50	8000 U 10000 I	8000 Est	20 U 30 I	OPX	1988 U
GAIA Spacer Grid	2	12	72	1 U 1 I	LTA	2012
718 HMP™ Spacer Grid	42	11000	11000	18 U 24 I	OPX	1998
GAIA uses same HMP™ Spacer Grid	-	-	-	-	-	-
W17x17 MSMG Spacer Grid	12	2300	6900	4 U 8 I	OPX	Not Stated
GAIA IGM Spacer Grid	2	12	36	1 U 1 I	LTA	2012
W17x17 Top Nozzle	70	33000	33000	7 U 63 I	OPX	1996
GAIA uses same Top Nozzle	-	-	-	-	-	-
W17x17 Bottom Nozzle (TRAPPER™)	70	33000	33000	6 U 64 I	OPX	1996
W17x17 Bottom Nozzle (GRIP™)	2	12	12	1 U 1 I	LTA	2012
MONOBLOC™ GT	90	38000	570000 Est.	10 U 80 I	OPX	1998
Q12™ GT	[ ]	[ ]	Not Stated	1 U 10 I	LTA/OPX	2010

3.3 Design Evaluation

The fuel system design bases must reflect these four objectives: (1) the fuel system is not damaged as a result of normal operation and AOOs, (2) fuel system damage is never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for postulated accidents, and (4) coolability is always maintained. To satisfy these objectives, acceptance criteria are needed for fuel system damage, fuel rod failure, and fuel coolability. The design basis for each criterion remains the consistent with those in the Advanced Mark-BW fuel assembly (Reference 10).

3.3.1 Fuel System Damage Criteria

The design criteria relating to the fuel system damage should not be exceeded during normal operation including AOOs. Fuel rod failure should be precluded and fuel damage criteria should ensure that fuel system dimensions remain within operational tolerances and that functional capabilities are not reduced below those assumed in the safety analysis. Each damage mechanism listed in SRP Section 4.2 will be reviewed to confirm that the design criteria are not exceeded during normal operation for the GAIA design.

3.3.1.1 Stress

The design criteria for stress are that the stress intensities for GAIA fuel assembly components shall be less than the stress limits based on the American Society of Mechanical Engineers Code, Section III criteria (Reference 7). These design criteria are consistent with the acceptance criteria of SRP Section 4.2; therefore, the stress criteria are acceptable for application to the GAIA fuel design.

A deterministic method is used to obtain the most limiting stress value provides the most conservative stress value for each fuel assembly component. Positive margin to the design criteria is shown for each of the fuel assembly components; therefore, the NRC staff concludes that the fuel assembly design satisfies the design criteria for design stress.

3.3.1.2 Cladding Strain

The design criterion for strain is that the GAIA fuel rod transient strain (elastic plus plastic) limit should not exceed 1 percent for Condition I and II events. This criterion is intended to preclude excessive cladding deformation during normal operation and AOOs. This design criterion is consistent with the acceptance criteria of SRP Section 4.2; therefore, the strain criterion is acceptable for application to the GAIA fuel design.

The analysis of the cladding strain uses the approved COPERNIC code (Reference 2) to determine the cladding strain by evaluating the cladding circumferential changes before and after a linear heat rate (LHR) transient. The 1 percent strain limit corresponds to a transient LHR that is greater than the maximum transient the fuel rod is expected to experience Condition I and II events. Therefore, the NRC staff concludes that the fuel assembly design criteria for cladding strain are met.

3.3.1.3 Cladding Fatigue

The design criterion for cladding fatigue is that the GAIA maximum fuel rod fatigue usage factor shall not exceed 0.9. This design criterion is consistent with the acceptance criteria of SRP Section 4.2; therefore, this cladding fatigue criterion is acceptable for application to the GAIA fuel design.

The methodology used for determining the cladding fatigue is outlined in Reference 3. The analysis used a fuel rod life of 10 years and a vessel life of 40 years; therefore, the fuel rod will experience 25 percent of the number of transients that the vessel will. The analysis uses all the Condition I and II events and one Condition III event to determine the total cladding fatigue usage factor. The maximum fatigue usage factor was determined to be well below the design criteria limit. Since the methodology is consistent with the guidance in SRP Section 4.2 and the maximum fatigue is well below the design criteria limit, it is demonstrated that the cladding fatigue acceptance criterion has been met.

3.3.1.4 Fretting

The design criteria for fretting are that the GAIA fuel assembly design shall be shown to have no failure due to fretting (Reference 9). This criterion is conservative with the acceptance criteria of SRP Section 4.2; therefore, the fretting criteria are acceptable for application to the GAIA fuel design.

Framatome performed extensive autoclave testing using expected EOL condition for the GAIA fuel assemblies. Fretting wear and performance testing were performed at the HERMES-P (Cadarache, France) and PHFT (Richland, Washington) flow test facilities. 1000 hour endurance flow tests were performed and followed up by additional tests at the PETER loop (Erlangen Germany). Additionally, an individual component pressure drop tests were performed at MAGALY test loop (Le Creusot, France). Evaluations of this extensive testing showed that the GAIA fuel assembly is expected to meet all criteria though EOL. Therefore, Framatome has demonstrated that the GAIA fuel has the ability to meet this criterion.

3.3.1.5 Oxidation, Hydriding, and Crud Buildup

The design criteria for oxidation, hydriding, and crud buildup are that the GAIA fuel rod cladding best-estimate corrosion shall not exceed 100 microns. There is not a defined limit on hydrogen pickup for the cladding. The M5® cladding material fuel rods are expected to have less than 50 microns of oxidation at peak rod burnup of 62-gigawatt day per metric tons of uranium (GWd/MTU). Hydrogen pickup is a material dependent property that is driven by the alloying elements and accelerated by thicker oxide layers. Initial hydrogen pickup is limited by smart manufacturing processes that remain unchanged for GAIA. Additionally, the M5® cladding material has an optimized resistance to hydrogen pickup due to its alloying and excellent oxidation layer buildup performance.

These criteria are intended to preclude potential fuel system damage mechanisms. The SRP does not specify limits on cladding oxidation and crud but does specify that their effects should be accounted for in the thermal and mechanical analyses performed for the fuel accounts for the corrosion based on a database established for the M5® cladding material from the in-reactor performance. This performance is based upon a long history of the M5® cladding material, which remains unchanged in its application to the GAIA FA. It is, therefore, not a subject of detailed review in this TR. The methodology and limits defined in Reference 2 are applicable and acceptable in the evaluation of the GAIA FA. Additionally, this is acceptable because it uses realistic data that is representative of the material and burnup limits for the GAIA fuel assembly design.

Based on the data for M5® cladding material under prototypical irradiation conditions, the oxidation and hydrogen pickup rates are well below the criteria limit. Because crud is included as part of the oxidation measurement, the crud is also limited and well within the total acceptable range. Therefore, it is demonstrated that the oxidation, hydriding, and crud buildup for the GAIA fuel assembly design have met the acceptance criteria.

3.3.1.6 Fuel Rod Bow

The design criterion for fuel rod bow is that the fuel rod bowing shall be evaluated with respect to the mechanical and thermal-hydraulic performance of the fuel assembly. There is not a specific limit for fuel rod bow specified in SRP Section 4.2; the SRP only requires that rod bow be included in the design analysis.

The methodology for fuel rod bow was approved in Reference 12. This database is representative of Zircaloy clad fuel. Because M5® cladding grows at a lower rate under irradiation conditions, the database for Zircaloy is conservative relative to the M5® performance. This approach remains unchanged and has been previously approved in Reference 9. Therefore, the NRC staff concludes that use of this database for predicting the rod bow of M5® clad fuel and continuing use of the penalty generated by the Zircaloy database for M5® fuel is conservative and acceptable for use.

3.3.1.7 Axial Growth

The design criteria for axial growth are that the GAIA fuel assembly-to-reactor internals gap allowance and the fuel assembly top nozzle-to-fuel rod gap allowance shall be designed to provide positive clearance during the assembly lifetime. These design criteria are consistent with the acceptance criteria of SRP Section 4.2; therefore, the axial growth criteria are acceptable for application to the GAIA fuel design.

Tolerances are combined in an appropriate manner and treated consistently. The lowest clearance values are/will be obtained at EOL and in all evaluations, positive clearance remained at EOL under the worst conditions. Axial growth of the GAIA FA is driven by the irradiated growth of the FA's GTs, in this case Q12™. The irradiated growth performance for Q12™ was reviewed and approved in Reference 5. Therefore, the NRC staff concludes that the GAIA fuel design meets the axial growth acceptance criteria subject to completion of L&C #3 to validate that the LTA EOL measurements are within the expected range of performance.

3.3.1.8 Fuel Rod Internal Pressure

The design criterion for fuel rod internal pressure is that the fuel system will not be damaged due to excessive internal pressure. Fuel rod internal pressure is limited to that which would cause (1) the diametral gap to increase due to outward creep during steady-state operation or (2) reorientation of the hydrides in the radial direction in the cladding. These design criteria have been applied in previous fuel assembly designs (Reference 10) and will continue to be valid since the parameters used in the methodology remain unchanged. Therefore, these criteria are acceptable for application to the GAIA fuel design.

The fuel rod internal pressure analysis uses the COPERNIC code with the methodology approved in Reference 2. This analysis, performed on a plant-specific basis, includes the use of the most limiting manufacturing variations and a bounding power history for that plant. If the bounding analysis does not meet the fuel rod internal pressure criteria, then on a cycle-specific basis a rod-specific analysis using the actual power history and manufacturing data for that rod can be performed to demonstrate that the internal rod pressure criteria are satisfied. These dual analysis paths using the approved methodology are acceptable for use because they will demonstrate that the fuel rod internal pressure criterion is met.

3.3.1.9 Assembly Liftoff

The design criteria for assembly liftoff are that the GAIA fuel hold down springs must be capable of maintaining fuel assembly contact with the lower support plate during normal operating, Condition I and II events, except for the pump over-speed transient. The fuel assembly top and bottom nozzles shall maintain engagement with reactor internals and the holddown springs shall maintain positive holddown margin after a pump overspeed event. These design criteria are consistent with the acceptance criteria of SRP Section 4.2, except for the exclusion of the pump over-speed transient. However, it has been previously approved to exclude this transient; therefore, the assembly liftoff criteria are acceptable for application to the GAIA fuel design.

It should be noted that the NRC staff was not able to find a comprehensive evaluation of this exemption in past approvals. Since the precedent has been set and without cause to show a substantial increase in safety the NRC staff has no basis to reverse this exemption for the pump over-speed transient. The generic fuel assembly liftoff evaluations for GAIA does not show assembly lift but would be allowed in a plant specific evaluation consistent with this precedent.

Framatome performs a combination of deterministic and statistically based analysis and can demonstrate that during all conditions considered, except for the pump over-speed transient, the fuel assembly liftoff criteria are met. During the pump over-speed transient, the lift is small, and the hold-down spring deflection is less than the worst-case normal operating cold-shutdown condition. The hold-down spring is not compressed to a solid height for any operating condition. Therefore, the NRC staff concludes that for the GAIA fuel assembly design, the fuel assembly liftoff criteria are met.

3.3.2 Fuel Rod Failure Criteria

The design criteria relating to the fuel rod failure are applied in two ways. When they are applied to normal operation including AOOs, they are used as limits (SAFDLs) since fuel failure should not occur. When they are applied to postulated accidents, fuel failures are permitted and must be accounted for in the fission product releases. Fuel rod failure is defined as the loss of fuel rod hermeticity. Each fuel rod failure mechanism listed in SRP Section 4.2 will be reviewed to confirm that the design criteria are not exceeded during normal operation and are properly accounted for during postulated accidents for the GAIA design.

Whether or not fuel rod failure is allowed during a Condition III transient is a plant specific criterion regardless of the methodology applied. If a plant is restricted to no fuel failure based upon its licensing basis, then Framatome must demonstrate that criterion is satisfied, or the plant may need to submit a license amendment request (LAR) to remove that restriction, or to change the American national Standards Institute/American Nuclear Society event categorization for a specific event, based upon Framatome's methodology and/or to justify the change in consequences for the event.

3.3.2.1 Internal Hydriding

The design criterion for internal hydriding is that the internal hydriding shall be precluded by appropriate manufacturing controls. For the GAIA assembly design, hydriding is prevented by keeping the level of moisture and hydrogenous impurities within the fuel to very low levels. Framatome maintains the fabrication level for total hydrogen in the fuel pellets to a level that is lower than the SRP Section 4.2 value of 2 parts per million. This design criterion is consistent with the acceptance criteria of SRP Section 4.2 and is acceptable.

Framatome maintains the low hydrogen levels in the fuel rod through manufacturing controls. Because these controls will remain in place for the GAIA fuel assembly design and the limits are lower than the SRP Section 4.2 values, the design criteria will continue to be met with the GAIA fuel assembly design.

3.3.2.2 Cladding Collapse

The design criterion for cladding collapse is that the predicted creep collapse life of the fuel rod must exceed the maximum expected in-core life. The SRP states that if axial gaps in the fuel pellet column occur due to densification, the cladding has the potential to collapse into a gap. Because of the large local strains that accompany this process, any collapsed cladding is assumed to fail. Because the design criterion is consistent with the acceptance criteria of SRP Section 4.2, it is acceptable for application to the GAIA fuel assembly design.

Framatome uses their approved creep collapse methodology (Reference 4), to determine the potential for creep collapse of the GAIA fuel assembly design. This methodology uses conservative values to determine the creep collapse life of the fuel rod. Creep collapse is assumed when either the rate of creep ovalization exceeds [ ] or the maximum fiber stress exceeds the unirradiated yield strength of the cladding. Based on these definitions of creep collapse, the creep collapse lifetime was shown to be greater than 62 GWd/MTU. Therefore, the GAIA fuel assembly design is adequately designed to prevent creep collapse for a service life up to 62 GWd/MTU.

3.3.2.3 Overheating of Cladding

The design criterion for overheating of the cladding is that for a 95/95 tolerance level, DNB will not occur on a fuel rod during normal operation and AOOs. The SRP states that it has been traditional practice to assume that failures will not occur if the thermal margin criteria (i.e., DNB ratio) are satisfied. Because the design criterion is consistent with the acceptance criteria of SRP Section 4.2, it is acceptable for application to the GAIA fuel assembly design.

3.3.2.4 Overheating of the Fuel Pellets

The design criteria for overheating of the fuel pellets are that fuel pellet centerline melting shall not occur during normal operation and AOOs. These design criteria are consistent with the acceptance criteria of SRP Section 4.2; therefore, they are acceptable for application to the GAIA fuel assembly design.

SRP Section 4.2 states that this analysis should be performed for the maximum linear heat generation rate anywhere in the core, including all hot spots and hot channel factors, and should account for the effects of burnup and composition on the melting point. Framatome uses the COPERNIC computer code and fuel melt methodology (Reference 2) to determine the local LHR throughout the fuel rod lifetime that could result in centerline temperature predictions exceeding the limit. The typical generic fuel centerline melt LHR is higher than any expected LHR at the most limiting time of the cycle. If the peak LHR is not at BOL then the time in life must be determined and thermal conductivity degradation must be accounted for the centerline temperature predictions. Therefore, this analysis demonstrated that for the GAIA fuel assembly design the acceptance criteria are met.

3.3.2.5 Pellet Cladding Interaction (PCI)

There are no generally applicable criteria for PCI failure in SRP Section 4.2. The two criteria that should be applied in accordance with SRP Section 4.2 are that the uniform strain of the cladding should not exceed 1 percent and fuel melting should be avoided. Since both of these criteria were addressed previously in this SE, the criteria for PCI are satisfied and acceptable for the GAIA design.

3.3.2.6 Cladding Rupture

There is not a specific design limit associated with cladding rupture other than the requirements in 10 CFR 50.46, Appendix K. The cladding rupture correlation and supporting data were reviewed and approved for LOCA emergency core cooling system (ECCS) analyses in References 3, 9, and 16. Because this correlation was developed specifically for use in analyzing M5® cladding, the use of this correlation will provide the appropriate cladding rupture evaluations for the GAIA fuel assembly design under accident conditions.

Clad swelling and rupture requirements following a postulated LOCA are included in the NRC-approved ECCS evaluation models. Emergency core cooling performance is addressed in plant-specific analyses using NRC-approved methods.

3.3.3 Fuel Coolability

For postulated accidents in which severe damage might occur, core coolability must be maintained as required by GDC 27 and 35. Coolability, or coolable geometry, has traditionally implied that the fuel assembly retains its rod bundle geometry with adequate coolant channels to permit the removal of residual heat.

Section 4.2, Appendix B of Reference 1 provides interim limits for reactivity insertion accidents (RIAs). The new guidance being developed by the NRC is contained in draft RG (DG) 1327, "Pressurized Water Reactor Control Rod Ejection and Boiling Water Reactor Control Rod Drop Accidents." A licensee should consider the most up-to-date guidance and analytical limits at the time of submittal. Alternative means to demonstrate compliance will be considered on a case-by-case basis.

These criteria will be met as long as Framatome or licensee uses NRC approved methods for RIAs and demostrates that the appropiate limits are met including radiological consequences (L&C #5).

3.3.3.1 Cladding Embrittlement

To meet the requirements of 10 CFR 50.46, as it relates to LOCA, acceptance criteria of 2200 degrees Fahrenheit on peak cladding temperature and 17 percent on maximum cladding oxidation must be met. Framatome has demonstrated through high-temperature oxidation and quenching tests that the M5® cladding can meet these limits. The data and analysis to support this conclusion were reviewed and approved in Reference 3. Further, Reference 3 concluded that the Baker-Just correlation is conservative for determining high-temperature M5® oxidation for LOCA analysis and; therefore, is acceptable for LOCA ECCS analyses. Since the Baker-Just correlation is conservative and is required in accordance with 10 CFR 50.46 Appendix K, these criteria will be met without any modification needed to the applicable ECCS evaluation models.

If Framatome chooses to use their best-estimate plus uncertainty realistic large break LOCA methodology (Reference 16) and utilize the Cathcart-Powell (CP) oxidation correlation, then the associated limitation on the oxidation criterion, 13 percent, applies to the evaluation of the GAIA fuel assembly design. Cladding embrittlement evaluations are done outside of the methodology discussed in this TR. Emergency core cooling performance is addressed in plant-specific analyses using NRC-approved methods.

3.3.3.2 Violent Expulsion of Fuel

In severe RIAs, such as a rod ejection event, the large and rapid deposition of energy in the fuel can result in melting, fragmentation, and dispersal of fuel.

Fuel cladding failure may occur almost instantaneously during the prompt fuel enthalpy rise (due to PCMI) or may occur as total fuel enthalpy (prompt + delayed), heat flux, and cladding temperature increase. For calculating fuel enthalpy for assessing PCMI failures, the prompt fuel enthalpy rise is defined as the radial average fuel enthalpy rise at the time corresponding to one pulse width after the peak of the prompt pulse. For assessing high cladding temperature failures, the total radial average fuel enthalpy (prompt + delayed) should be used.

This criterion will be met as long as Framatome or Licensee uses NRC-approved methods for RIA and demostrates that the appropiate limits are met including radiological cosequences (L&C #5).

3.3.3.3 Fuel Rod Ballooning

To meet the requirements of 10 CFR 50.46, as related to the evaluation of ECCS performance during accidents, burst strain and flow blockage caused by ballooning of the cladding must be accounted for in the analysis of the core flow distribution. Framatome developed new ballooning and flow blockage models for M5® cladding which were reviewed and approved in

Reference 3. Since these models were developed specifically for use in analyzing M5® cladding, the use of these models will provide the appropriate fuel rod ballooning for the GAIA fuel assembly design.

Emergency core cooling performance is addressed in plant-specific analyses using NRC-approved methods.

3.3.3.4 Fuel Assembly Structural Damage from External Forces

Earthquakes and postulated pipe breaks in the reactor coolant system would result in external forces on the fuel assembly. During these events, fuel system coolability should be maintained and damage should not be so severe as to prevent control rod insertion when required. The design criteria for fuel assembly structural damage from external forces are divided into three categories:

- Operating Basis Earthquake (OBE) – Allow continued safe operation of the fuel assembly following an OBE event by ensuring the fuel assembly components do not violate their dimensional requirements.
- Safe Shutdown Earthquake (SSE) – Ensure safe shutdown of the reactor by maintaining the overall structural integrity of the fuel assemblies, control rod insertability, and a coolable geometry within the deformation limits consistent with the ECCS and safety analysis.
- LOCA or SSE+LOCA – Ensure safe shutdown of the reactor by maintaining the overall structural integrity of the fuel assemblies and a coolable geometry within deformation limits consistent with the ECCS and safety analyses.

These design criteria are consistent with SRP Section 4.2 guidance; therefore, they are acceptable for application to the GAIA fuel assembly design.

Framatome used the methodology in Reference 6 to perform generic evaluations of the structural damage from external forces. These analyses considered the horizontal and vertical impacts on the fuel assembly. The analysis shall include generic evaluations of the impact on the GAIA fuel assembly design when it is located in a mixed core on a plant specific basis at the time the licensee implementation. Various core loading patterns and locations in the core were utilized for the mixed core analysis impact. The results showed that the combined loads on the GAIA fuel assembly were small enough that coolable geometry is always maintained. The analysis results demonstrate that coolable geometry can be maintained under all the analyzed conditions; therefore, demonstrate that the acceptance criteria are met.

Any deformation that goes from the linear to the non-linear range is not acceptable currently. A supplement to Reference 6 will be needed to extend acceptable deformation in the non-linear region.

3.4 Design Update Process

Per letter request (Reference 19), Section 9.0 of the TR, has been withdrawn from consideration. This leaves the update process for GAIA to only that which is allowed per

10 CFR 50.59 and other existing regulations. Specifically, the EMF-92-116(P)(A) TR is not applicable to GAIA.

4.0 LIMITATIONS AND CONDITIONS

The NRC staff approves the the use of this TR subject to the following L&Cs:

1) This GAIA fuel assembly design is approved for use with low enrichment uranium (LEU) fuel, which has been enriched to less than or equal to 5 percent.

2) The GAIA fuel assembly design is licensed for a maximum fuel rod burnup of 62,000 Megawatt-days/metric ton of Uranium.

3) The final LTA program PIE report shall be submitted to NRC staff prior to any reload batch of GAIA assemblies reaching the third cycle of operation.

4) (Removed)

   Per letter request (Reference 19), Section 9.0 of the TR, has been withdrawn from consideration. This leaves the update process for GAIA to only that which is allowed per 10 CFR 50.59 and other existing regulations. Specifically, the EMF-92-116(P)(A) TR (Reference 8) is not applicable to GAIA.

5) As part of the plant-specific LAR implementing GAIA, the licensee must demonstrate acceptable performance of GAIA under RIA conditions, including fuel damage, coolable geometry, and radiological consequences, using approved methods. Current guidance and analytical limits are found in SRP 4.2 Appendix B. Newer guidance is expected soon (e.g., DG-1327). The licensee should consider the most up-to-date guidance and analytical limits at the time of submittal. Alternative means to demonstrate compliance will be considered on a case-by-case basis.

5.0 CONCLUSION

The NRC staff reviewed the acceptance criteria and generic and proposed analysis methodology presented by Framatome in TR ANP-10342(P), Revision 0, "GAIA Fuel Assembly Mechanical Design," and determined that the criteria and proposed analysis methods are performed in accordance with the guidance provided in SRP Section 4.2. The NRC staff finds the criteria and proposed analysis methods outlined in this TR acceptable based on the determinations provided in the technical evaluation section of this SE and concludes that the TR is acceptable for referencing by licensees.

There were no requests for additional information questions issue as part of this review. The missing evaluation sections, that are required per Reference 1 were accommodated by the issuance of L&Cs on this TR or by the additional information provided in Reference 18.

Therefore, on the basis of the above review and justification, the NRC staff concludes that the GAIA fuel assembly design is acceptable for use in Westinghouse three-loop and four-loop design reactors which use a 17 x 17 fuel rod array with LEU fuel subject to the L&Cs included in this SE.

6.0 REFERENCES

1) NUREG-0800 – Chapter 4, Section 4.2, Revision 3, "Fuel System Design," U.S. Nuclear Regulatory Commission, March 2007 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML070740002).

2) BAW-10231P-A, Revision 1, "COPERNIC Fuel Rod Design Computer Code," Framatome ANP, Inc., January 2004 (ADAMS Package Accession No. ML042930233).

3) BAW-10227P-A, Revision 1, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel," Framatome ANP, Inc. June 2003 (ADAMS Package Accession No. ML15162B043).

4) BAW-10084P-A, Revision 3, "Program to Determine In-Reactor Performance of BWFC Fuel Cladding Creep Collapse," B&W Nuclear Technologies, July 1995 (ADAMS Accession No. ML14191B170, nonpublic).

5) ANP-10334P-A, Revision 0, "Q12™ Structural Material," AREVA Inc., September 2017 (ADAMS Package Accession No. ML17320A119).

6) ANP-10337P-A, Revision 0, "PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations," Framatome Inc., April 2018 (ADAMS Package Accession No. ML18144A816).

7) American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1992 Edition

8) EMF-92-116P-A, Revision 0, "Generic Mechanical Design Criteria for PWR Fuel Designs," Siemens Power Corporation, February 1999 (ADAMS Accession No. ML003681168, nonpublic).

9) BAW-10240P-A, Revision 0, "Incorporation of M5™ Properties in Framatome ANP Approved Methods," Framatome ANP Inc., May 2004 (ADAMS Package Accession No. ML042800308).

10) BAW-10239P-A, Revision 0, "Advanced Mark-BW Fuel Assembly Mechanical Design Topical Report," Framatome ANP Inc., July 2004 (ADAMS Package Accession No. ML042820190).

11) ANF-89-060(P)(A) and Supplement 1, "Generic Mechanical Design Report High Thermal Performance Spacer and Intermediate Flow Mixer," Advanced Nuclear Fuels Corporation, March 1991.

12) XN-75-32P-A, Supplements 1, 2, 3,.& 4, "Computational Procedure for Evaluating Fuel Rod Bowing," Exxon Nuclear Company, Inc., October 1983 (ADAMS Accession No. ML081710709, nonpublic).

13) BAW-10243P-A, "Statistical Fuel Assembly Hold Down Methodology," Framatome ANP Inc., September 2005 (ADAMS Package Accession No. ML053610044).

14) Regulatory Guide 1.77, "Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors," U.S. Atomic Energy Commission, May 1974 (ADAMS Accession No. ML003740279).

15) Letter from Gary Peters to the USNRC, "Request for Review and Approval of ANP-10342P, 'GAIA Fuel Assembly Mechanical Design,'" AREVA Inc., December 2016 (ADAMS Accession No. ML16362A278).

16) EMF-2103P-A, Revision 3, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," AREVA Inc., June 2017 (ADAMS Accession No. ML16286A579).

17) Letter from Gary Peters to the USNRC, "Response to Request for Comment on Draft Safety Evaluation for ANP-10342, 'GAIA Fuel Assembly Mechanical Design'," Framatome, December 20, 2018 (ADAMS Accession No. ML18360A171).

18) ANP-10342Q1P, Revision 0, "GAIA Fuel Assembly Mechanical Design Additional Information," December 2018 (ADAMS Accession No. ML18355A067).

19) Letter from Gary Peters to the USNRC, "Additional Information Regarding ANP-10342P, "GAIA Fuel Assembly Mechanical Design" ," Framatome, September 6, 2019 (ADAMS Accession No. ML19253A050)

Attachment: Comment Resolution

Principal Contributor: J. Dean, NRR/DSS

Date: September 24, 2019

RESOLUTION OF COMMENTS BY THE OFFICE OF NUCLEAR REACTOR REGULATION ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT ANP-10342P, REVISION 0, "GAIA FUEL ASSEMBLY MECHANICAL DESIGN"

FRAMATOME, INC.

PROJECT NO. 728/DOCKET NO. 99902041

This attachment provides the U.S. Nuclear Regulatory Commission (NRC) staff's review and disposition of the comments made by Framatome Inc. (Framatome) on the draft safety evaluation (SE) for Topical Report (TR) ANP-10342P, Revision 0, "GAIA Fuel Assembly Mechanical Design." Framatome provided the comments by letter dated December 20, 2018 (Agencywide Documents Access and Management System Accession No. ML18360A171). Reference 2 in this attachment refers to Reference 2 of that letter.

Page	Line	Proposed Change/Comment	NRC Resolution of Proposed Change/Comment
1	19-20	Replace "this TR extends the use of the fuel design change process..." with "this TR implements a fuel design change process similar to the one..." ANP-10342P is not dependent upon EMF-92-116.	The NRC staff accepts the proposed change. The change was made accordingly in the final SE.
2	23, 25-28	Replace "This TR extends the use of the fuel design change process..." with "This TR implements a fuel design change process similar to the one..." and delete the second sentence of this paragraph. The GAIA change process is self-contained and does not use methods and criteria from EMF-92-116. The independence from EMF-92-116 is reinforced by the additional information provided in Reference 2 of this letter.	The additional information provided justification of the independence. The NRC staff accepts the proposed change. The change was made accordingly in the final SE.
6	7-9	Framatome proposed a re-wording of the internal pressure criteria in Reference 2 of this letter that is consistent with SRP Section 4.2 and current practice, including the analysis supporting ANP-10342P. The SE should be updated to reflect the markups in Reference 2, which will be included in the approved version of the topical report.	The staff agrees and will confirm the write up in the -A version of the TR.

Page	Line	Proposed Change/Comment	NRC Resolution of Proposed Change/Comment
7 8 9 10	43 34 4, 19 15	Framatome proposed in Reference 2 of this letter to add specific sections in ANP-10342P for the following evaluation areas: overheating of cladding, excessive fuel enthalpy, bursting, cladding embrittlement, violent expulsion of fuel, and fuel rod ballooning. These new sections identify that the criteria are included in NRC-approved methodology topical reports. These criteria are not evaluated as part of the generic topical report but will be evaluated in plant-specific analyses using NRC-approved methods. This SE should be updated to reflect only the information in Reference 2 for these criteria.	Staff acknowledges that the criteria are evaluated outside of this TR. Some changes were made to state this but acceptance criteria for GAIA were added for the use those outside methods as they apply to GAIA.
11	37-38	Framatome interprets Section 3.4 to mean that minor changes require discussion or notification per clarification #3, but this discussion / notification can occur after implementation of the change. Therefore, NRC's stated right to declare that a change is subject to review and approval could occur after implementation of the change. No change to the SE is required.	The design update process evaluation section was completely rewritten for clarity and to establish the notification requirement for minor and major changes.
12	1-2	Framatome understands the request for notification of minor changes. For clarification, Framatome recommends: "Should Framatome decide that the fuel update meetings are no longer going to be held then a report of all the minor mechanical design changes shall be made within a year after first implementation of the change in a GAIA reload." This wording will also remove the obligation to submit an annual report when no changes have been made.	The NRC staff accepts the suggested clarification. The final SE was changed accordingly. L&C reworded.
12	1-2	The requirement to discuss minor changes at the fuel performance meeting or submit a report of changes should be identified in Section 4.0, Limitations and Conditions, because the requirement is not stated in ANP-10342P.	The requirement to discuss changes at fuel performance meeting has been removed. Alternate reporting has placed in SE. L&C reworded

Page	Line	Proposed Change/Comment	NRC Resolution of Proposed Change/Comment
12	17-20	Limitation and condition #4 can be removed. The use of approved CHF correlations and mixed core methods has been added to ANP-10342P in Reference 2 of this letter.	Framatome provided adequate information to convince the NRC staff that limitation and condition #4 should be removed. The final SE was modified accordingly. There are no additional restrictions on the use of CHF correlations that have approved for the use with GAIA fuel.
12	22-29	Framatome does not object to using a modern control rod ejection methodology. However, because reactivity initiated accidents are outside the scope of ANP-10342P, Framatome believes it is not appropriate to include this limitation here. The implementation provisions in the final Regulatory Guide resulting from DG-1327 will dictate when the guidance should be back fit or forward fit on a licensee.	Discussion of the use of DG-1327 has largely been removed. L&C condition on RIA has be re-written to state that plants LAR to adopt GAIA must include evaluation of RIA including a justifiable acceptance criteria.
12	39-41	The highlighted statement should be deleted. Per LIC-500, additional restrictions to the topical report imposed by the NRC staff should be clearly stated as limitations and conditions. In the absence of specific limitations and conditions, the SE approves use of the topical report as written, including information not explicitly addressed in the SE. If the NRC staff does not agree with this comment, then additional information must be added to the SE.	Statement removed with additional rewording
12	46	This statement can be removed. In Reference 2, Framatome has added a statement to ANP-10342P about each additional criterion in SRP Section 4.2 that is not evaluated generically in the topical report.	Statement has been removed

GAIA Fuel Assembly Mechanical Design

ANP-10342NP
Revision 0

Topical Report

December 2016

AREVA Inc.

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

List of Tables

List of Figures

Nomenclature

Acronym	Definition
AOA	Axial Offset Anomaly
AOO	Anticipated Operational Occurrence
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BOL	Beginning of Life
BPVC	Boiler and Pressure Vessel Code
CFM	Centerline Fuel Melt
CFR	Code of Federal Regulations
CHF	Critical Heat Flux
CUF	Cumulative Usage Factor
DNB	Departure from Nucleate Boiling
DNBR	Departure from Nucleate Boiling Ratio
ECCS	Emergency Core Cooling System
EFPD	Effective Full Power Days
EOL	End of Life
FIV	Flow-Induced Vibration
GWd/MTU	Gigawatt Day per Metric Tons of Uranium
IGM	Intermediate GAIA Mixer
LHGR	Linear Heat Generation Rate
LOCA	Loss of Coolant Accident
LTA	Lead Test Assembly
MOL	Middle of Life
MSMG	Mid Span Mixing Grid
NRC	U.S. Nuclear Regulatory Commission
OBE	Operational Basis Earthquake
PCI	Pellet to Cladding Interaction
PIE	Post Irradiation Examination
PWR	Pressurized Water Reactor
QD	Quick Disconnect
RCCA	Rod Cluster Control Assembly
RIA	Reactivity Initiated Accident
SAFDL	Specified Acceptable Fuel Design Limit

Acronym	Definition
SFP	Spent Fuel Pool
SIE	Self-Induced Excitation
SRP	Standard Review Plan
SSE	Safe Shutdown Earthquake
TCS	Transient Cladding Strain
U.S.	United States

ABSTRACT

The purpose of this topical report is to present the GAIA fuel assembly mechanical design and an evaluation of its mechanical performance on a generic basis. The GAIA design is intended for use in Westinghouse type plants with a 17x17 fuel rod array. The GAIA fuel assembly design is a combination of previously utilized and advanced performance components. This topical report is intended to be referenced in site specific licensing basis documents for plants using the GAIA design.

A discussion of the current regulatory guidance related to fuel assemblies is presented, based on the Nuclear Regulatory Commission's (NRC) Standard Review Plan (SRP), NUREG-0800 Chapter 4.2. A comparison is presented of applicable NUREG-0800 Chapter 4.2 acceptance criteria and the specified acceptable fuel design limits (SAFDLs) established for the GAIA design. The SAFDLs established for the GAIA design have been previously approved for other AREVA fuel assembly designs.

A description of the GAIA fuel assembly design is provided. The components which have been previously utilized and those which are new are identified.

The fuel assembly mechanical tests which have been performed on the GAIA fuel assembly design are summarized.

The relevant operating experience with the GAIA fuel assembly design is summarized.

The Lead Test Assembly (LTA) programs which are ongoing to obtain information regarding the performance of the GAIA fuel assembly design are described.

An evaluation of the performance of the GAIA fuel assembly design for representative operating conditions is presented and compared to the established criteria.

1.0 INTRODUCTION

AREVA has developed the GAIA fuel assembly design for use in Westinghouse three- and four-loop reactors using a 17x17 fuel rod array. The GAIA design is a combination of previously utilized components and advanced performance components. The primary new features are: GAIA spacer grids, GRIP™ bottom nozzle, and Q12™ guide tube material.

Section 3.0 provides a summary of the regulatory guidance provided in NUREG-0800 Chapter 4.2 related to fuel assemblies, and a comparison to the SAFDLs established for the GAIA fuel assembly design. Section 4.0 describes the GAIA design, highlighting its distinguishing features. Section 5.0 summarizes the mechanical testing performed on the GAIA fuel assembly design. Section 6.0 presents the component operating experience. Section 7.0 presents the associated LTA programs. Section 8.0 provides the results of an evaluation of the GAIA fuel assembly under representative conditions against the SAFDLs defined in Section 3.0 of this report. The SAFDLs established for the GAIA fuel assembly performance are consistent with NUREG-0800 Chapter 4.2 and those previously established in topical reports reviewed and approved by the NRC.

Evaluations of the GAIA fuel assembly, which will reference the NRC-approved version of this topical report, will be performed on a plant-specific basis.

2.0 SUMMARY

2.1 *Fuel Assembly Description*

The GAIA fuel assembly is a combination of evolutionary design improvements and advanced performance components, which results in high reliability, robustness, and performance. A general description of the GAIA fuel assembly is provided in Figure 2 1, with additional component descriptions organized by reliability, robustness and performance.

Reliability:

The GAIA fuel assembly includes multiple components and features designed to ensure fuel rod integrity and reliability.

The new GAIA spacer grid design incorporates a spring hull feature which emulates the 8-line fuel rod support concept of AREVA's HTP™ spacer grid design. This 8-line grid to cladding interface has proven to be highly resistant to grid to rod fretting wear.

The new GRIP™ bottom nozzle design incorporates a bullet-nose feature at each fuel rod location, which emulates the stabilized flow concept of AREVA's proven FUELGUARD™ bottom nozzle design. In addition, a counter-bore feature located above each bullet–nose creates a physical interface with the fuel rod tip protecting it from excessive fuel rod vibration. The GRIP™ bottom nozzle includes a high strength, high filter efficiency, filter plate resulting in a design that is resistant to debris fretting wear.

The GAIA fuel assembly design incorporates AREVA's HMP™ end spacer grids. This Alloy 718 grid design has proven to be highly resistant to grid to rod fretting wear, and in combination with the GRIP™ bottom nozzle provides significant fretting wear protection in the inlet region.

The GAIA fuel assembly design incorporates AREVA's M5® alloy as fuel rod cladding material. The optimized chemical composition of M5® and its refined microstructure provide enhanced resistance to corrosion and very low hydrogen uptake. This translates to less embrittlement, greater reliability at higher burnups, and anticipated compliance with future loss of coolant accident (LOCA) & reactivity initiated accident (RIA) requirements.

The GAIA fuel assembly design incorporates AREVA's optimized fuel pellet end face geometry, reducing the probability for chipping and therefore the risk of failure through pellet to cladding interaction.

Robustness:

The GAIA fuel assembly includes multiple components and features designed to provide fuel assembly robustness.

The lateral stiffness of the structural cage is increased by the use of AREVA's existing MONOBLOC™ guide tube design, in combination with a larger overall outer diameter and an eight point grid-to-guide tube weld pattern. The MONOBLOC™ design provides a thick-walled tube in the lower dashpot region. The increase in the guide tube outer diameter, and the attachment of the GAIA spacer grids to the guide tubes by an [ ] increases stiffness along the entire length of the cage.

The MONOBLOC™ guide tubes incorporate AREVA's new Q12™ material. Q12™ is an evolutionary development of the current M5® alloy, and offers higher irradiation-induced creep resistance and therefore increased dimensional stability. Based on the chemical composition modifications relative to M5®, the higher irradiation-induced creep resistance is achieved while maintaining acceptable corrosion resistance.

The new GAIA spacer grid maintains adequate elastic strength to support external loads caused by seismic and LOCA events, consistent with AREVA's current spacer grid designs. In addition, the spring hull feature provides localized grid cell reinforcement which has a stiffening and stabilizing effect on the overall grid geometry and results in a grid that is resistant to a localized buckling (or "racking") failure mode. Instead, the deformation of the grid is uniformly distributed throughout each row, and the geometric changes of the guide tube and fuel rod arrays remain relatively small.

GAIA incorporates a relaxed Alloy 718 HMP™ spacer grid at the upper end grid location. The relaxation of the cells decreases the axial compressive stresses on the fuel rod in order to mitigate fuel rod bow.

Performance:

The GAIA fuel assembly includes multiple components and features designed for high thermal performance and efficient fuel management.

The new GAIA spacer grid design incorporates mixing vanes on the trailing edge of the inner strips to ensure efficient mixing for demanding fuel managements and power up-rate operating conditions.

The new GAIA spacer grid is complimented by the IGM grid, which also incorporates trailing edge mixing vanes to enhance thermal performance.

The GAIA fuel rod design can incorporate a pellet with [ ] theoretical density, in order to increase uranium loading and provide fuel management flexibility.

2.2 *Fuel Assembly Evaluation*

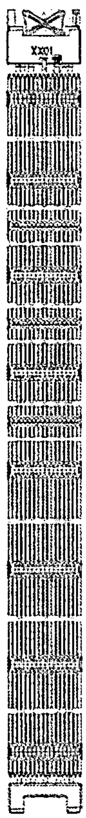
A review of the regulatory guidance related to fuel assembly design is provided. The GAIA fuel assembly is evaluated for conformance with the AREVA implementation of the guidance.

Tests are performed on the GAIA fuel assembly to provide input to the design evaluations. A description of each test is provided.

The most significant current operating experience for the GAIA fuel assembly is summarized in this report. The operating experience is both for individual components and for the fuel assembly (or portions thereof) as a whole.

The design evaluation results demonstrate that the SAFDLs established for the GAIA fuel assembly design are met. This design evaluation is performed for a representative plant and cycle to provide confidence that the fuel assembly will perform acceptably. Evaluations will be performed on a plant and cycle specific basis to assure that individual plant and cycle characteristics are reflected in the design evaluation to demonstrate that the SAFDLs are met.

Figure 2-1 GAIA Fuel Assembly Summary



- M5® GAIA Spacer Grids
  - Fretting resistance consistent with AREVA's HTP™ design
  - High thermal performance via trailing edge mixing vanes
- M5® Intermediate GAIA Mixer (IGM) Grids
  - Additional mixing consistent with AREVA's Advanced MK-BW design
- Alloy 718 HMP™ End Spacer Grids
  - Upper grid relaxed to mitigate fuel rod bow
- M5® Fuel Rods
  - High resistance to corrosion and hydrogen uptake
  - High density pellets
- Q12™ MONOBLOC™ Guide Tubes and Instrument Tube
  - Increased cross-sectional area to improve lateral stiffness
  - Q12™ material based on M5®, w/ improved creep properties
- Standard Reconstitutable Top Nozzle
  - 3-leaf holddown system with ¼-turn quick disconnect (QD)
- GRIP™ Bottom Nozzle
  - Improved filtering efficiency relative to AREVA designs
  - Stabilized flow consistent with AREVA's FUELGUARD™ design

3.0 REGULATORY REQUIREMENTS

A review of NUREG-0800 Chapter 4.2 guidance relevant to a fuel assembly design is provided in Table 3-1. The table identifies which acceptance criteria of NUREG-0800 Chapter 4.2 are applicable to this mechanical fuel assembly design topical report. For those acceptance criteria that are applicable, SAFDLs are established for the GAIA design and the section in the topical report where the SAFDL is evaluated is indicated, or it is acknowledged that the acceptance criteria are evaluated elsewhere.

Table 3-1 NUREG-0800 Chapter 4.2 Acceptance Criteria Matrix

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
Fuel System Damage	
1.A.i Stress, strain, or loading limits for spacer grids, guide tubes, thimbles, fuel rods, control rods, channel boxes, and other fuel system structural members should be provided. Stress limits that are obtained by methods similar to those given in Section III of the BPVC of the ASME are acceptable. Other proposed limits must be justified.	Section 8.1.1 Stresses and/or loads associated with normal operation, anticipated operational occurrences (AOO's), shipping, and handling shall be less than limits based on Section III of the American Society of Mechanical Engineers (ASME) Code for all components, unless otherwise specified. Maximum uniform hoop strain (elastic plus plastic) shall not exceed 1%.
1.A.ii The cumulative number of strain fatigue cycles on the structural members mentioned in item (i) above should be significantly less than the design fatigue lifetime, which is based on appropriate data and includes a safety factor of 2 on stress amplitude or a safety factor of 20 on the number of cycles. Other proposed limits must be justified.	Section 8.1.2 Maximum fatigue cumulative usage factor (CUF) is 1.0 for all components other than M5® fuel rod cladding. Maximum fatigue CUF is 0.9 for M5® fuel rod cladding.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.A.iii Fretting wear at contact points on the structural members mentioned in item (i) above should be limited. Fretting wear tests and analyses that demonstrate compliance with this design basis should account for grid spacer spring relaxation. The allowable fretting wear should be stated in the safety analysis report, and the stress and fatigue limits in items (i) and (ii) above should presume the existence of this wear.	Section 8.1.3 Fuel rod failures due to fretting shall not occur.
1.A.iv Oxidation, hydriding, and the buildup of corrosion products (crud) should be limited, with a limit specified for each fuel system component. These limits should be established based on mechanical testing to demonstrate that each component maintains acceptable strength and ductility. The safety analysis report should discuss allowable oxidation, hydriding, and crud levels and demonstrate their acceptability. These levels should be presumed to exist in items (i) and (ii) above. The effect of crud on thermal-hydraulic considerations and neutronic (AOA) considerations are reviewed as described in SRP Sections 4.3 and 4.4.	Section 8.1.4 Cladding peak oxide thickness shall not exceed a best-estimate predicted value of 100 microns.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.A.v Dimensional changes, such as rod bowing or irradiation growth of fuel rods, fuel assemblies, control rods, and guide tubes, should be limited to prevent fuel failures or a situation in which the thermal-hydraulic limits established in Section 4.4 are exceeded. Irradiation growth can result in a significant interference fit between the rod upper end cap and the upper nozzle (in a PWR), resulting in rod bowing. Control blade/rod, channel, and guide tube bow as a result of (1) differential irradiation growth (from fluence gradients), (2) shadow corrosion (hydrogen uptake results in swelling), and (3) stress relaxation, which can impact control blade/rod insertability from interference problems between these components. If interference is determined to be possible, tests are needed to demonstrate control blade/rod insertability consistent with assumptions in safety analyses. Additional in-reactor surveillance (e.g., insertion times) may also be necessary for new designs, dimensions, and materials to demonstrate satisfactory performance.	Section 8.1.5 There is no explicit design criterion for fuel rod bow. Departure from nucleate boiling ratio (DNBR) and linear heat generating rate (LHGR) burnup thresholds and penalties are calculated and considered on a cycle by cycle basis to address the thermal-hydraulic limits established in SRP 4.4. Clearance is required between the fuel rod and nozzles and between the fuel assembly and reactor core plates at end of life (EOL).

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.A.vi Fuel and burnable poison rod internal gas pressures should remain below the nominal system pressure during normal operation or other limits must be justified based on, but not limited to, the following minimum criteria. (1) No cladding liftoff during normal operation (2) No reorientation of the hydrides in the radial direction in the cladding (3) A description of any additional failures resulting from DNB caused by fuel rod overpressure during transients and postulated accidents (see Subsection II, item 1.B.vii)	Section 8.1.6 Internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation or (2) reorientation of the hydrides in the radial direction in the cladding. The criteria for DNB propagation are included in other NRC-approved evaluation methods.
1.A.vii Because unseating a fuel bundle may challenge control rod/blade insertion, an evaluation of worst-case hydraulic loads should be performed for normal operation, AOOs, and accidents. These worst-case hydraulic loads for normal operation should not exceed the holddown capability of the fuel assembly (either gravity or holddown springs). Hydraulic loads for this evaluation are reviewed as described in SRP Section 4.4.	Section 8.1.7 During normal operation conditions, the holddown springs shall maintain fuel assembly contact with the lower support plate. Assuming a pump over-speed transient, fuel assembly lift-off can occur but the fuel assembly top and bottom nozzles shall maintain engagement with reactor internal pins and the holddown springs shall maintain positive holddown margin after the event.
1.A.viii Control Rod Reactivity and Insertability	Control rod reactivity and insertability are applicable to the control rod itself, and therefore are not explicitly addressed in this fuel assembly mechanical design topical report.

NUREG-0800 Chapter 4.2 Acceptance Criteria	**GAIA Mechanical Topical Report SAFDL**
1.B.i Both internal and external sources of hydriding can cause a zirconium alloy component to fail. To prevent failure from internal hydriding (i.e., primary hydriding), the level of moisture and other hydrogenous impurities within the fuel is kept very low during fabrication. Acceptable moisture levels for Zircaloy-clad uranium oxide fuel should be no greater than 20 micrograms per gram (µg/g) (20 parts per million (ppm)). Current specifications of the American Society for Testing and Materials (ASTM),1989 edition, Standard C776-89, Part 45, for uranium oxide fuel pellets state an equivalent limit of 2 µg/g (2 ppm) of hydrogen from all sources. For other materials clad in Zircaloy tubing, an equivalent quantity of moisture or hydrogen can be tolerated. A moisture level of 2 milligrams of water per cubic centimeter of hot void volume within the Zircaloy cladding has been shown to be insufficient for primary hydride formation. External hydriding is caused by waterside corrosion in which the water reaction with the zirconium alloy results in zirconium hydrides as well as zirconium dioxide.	Section 8.2.1 Internal hydriding shall be precluded by appropriate manufacturing controls. External hydriding is addressed in acceptance criteria 1.A.iv.
1.B.ii If axial gaps in the fuel pellet column result from densification, the cladding has the potential to collapse into a gap (i.e., flattening). Because of the large local strains that accompany this process, collapsed (flattened) cladding is assumed to fail.	Section 8.2.2 Predicted creep collapse life of the fuel rod must exceed the maximum expected in-core life.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.B.iii Overheating of Cladding	Section 8.4.1 The criteria for departure from nucleate boiling are included in the NRC-approved critical heat flux correlation topical report for use with the GAIA fuel assembly.
1.B.iv Traditional practice has also assumed that failure will occur if centerline melting takes place. This analysis should be performed for the maximum linear heat generation rate anywhere in the core, including all hot spots and hot channel factors, and should account for the effects of burnup and composition on the melting point. For normal operation and AOOs, centerline melting is not permitted. For postulated accidents, the total number of rods that experience centerline melting should be assumed to fail for radiological dose calculation purposes. The centerline melting criterion was established to assure that axial or radial relocation of molten fuel would neither allow molten fuel to contact the cladding nor produce local hot spots. The assumption that centerline melting results in fuel failure is conservative.	Section 8.2.3 Fuel melting during normal operation and AOO's is precluded.
1.B.v Excessive Fuel Enthalpy	Section 8.4.2 The criteria for excessive fuel enthalpy during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.B.vi Pellet/Cladding Interaction	There are no generally applicable criteria for PCI or pellet to cladding mechanical interaction (PCMI) failures. The clad strain SAFDL relative to SRP acceptance criteria 1.A.i and the fuel melt SAFDL relative to SRP acceptance criteria 1.B.iv are used to ensure that the fuel rod design is acceptable. Therefore, PCI and PCMI are not explicitly addressed further in this fuel assembly mechanical design topical report.
1.B.vii Bursting	Section 8.4.3 Cladding swelling and rupture requirements are included in the NRC-approved loss-of-coolant accident (LOCA) evaluation models.
1.B.viii Mechanical Fracture	Mechanical fracturing is addressed by the SAFDL relative to SRP acceptance criteria 1.C.v, and therefore not addressed further in this fuel assembly mechanical design topical report.
Fuel Coolability	
1.C.i Cladding Embrittlement	Section 8.4.4 The criteria for cladding embrittlement during a LOCA are included in the NRC-approved LOCA evaluation methods.
1.C.ii Violent Expulsion of Fuel	Section 8.4.5 The criteria for violent expulsion of fuel during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.C.iii Generalized Cladding Melting	Generalized cladding melting is prevented by the more stringent SAFDL associated with SRP acceptance criteria 1.C.i, and therefore not addressed further in this fuel assembly mechanical design topical report.
1.C.iv Fuel Rod Ballooning	Section 8.4.6 Fuel rod ballooning requirements are included in the NRC-approved LOCA methods.
1.C.v Structural Deformation NOTE: Acceptance criteria for the evaluation of fuel assembly structural response to externally applied forces are contained in Appendix A Section IV.1 for LOCA and Section IV.2 for safe shutdown earthquake. Two principal criteria apply for the LOCA—(1) fuel rod fragmentation must not occur as a direct result of the blowdown loads and (2) the 10 CFR 50.46 temperature and oxidation limits must not be exceeded. The first criterion is satisfied if the combined loads on the fuel rods and components other than grids remain below the allowable values defined above. The second criterion is satisfied by an ECCS analysis. If combined loads on the grids remain below P(crit), as defined above, then no significant distortion of the fuel assembly would occur and the usual ECCS analysis is sufficient. If combined grid loads exceed P(crit), then grid deformation must be assumed and the ECCS	8.3.1 Operational basis earthquake (OBE) stress and load limits are set at the level A limits defined in the ASME Code, unless otherwise specified. Safe shutdown earthquake (SSE) and LOCA stress and load limits are set at the Level D limits defined in the ASME Code, unless otherwise specified.

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
analysis must include the effects of distorted fuel assemblies. An assumption of maximum credible deformation (i.e., fully collapsed grids) may be made unless other assumptions are justified. Control rod insertability is a third criterion that must be satisfied. Loads from the worst-case LOCA that requires control rod insertion must be combined with the SSE loads, and control rod insertability must be demonstrated for that combined load. For a PWR, if combined loads on the grids remain below P(crit), as defined above, then significant deformation of the fuel assembly would not occur and lateral displacement of the guide tubes would not interfere with control rod insertion. If combined loads on the grids exceed P(crit), then additional analysis is needed to show that the deformation is not severe enough to prevent control rod insertion. Two criteria apply to the SSE - (1) fuel rod fragmentation must not occur as a result of the seismic loads and (2) control rod insertability must be assured. The first criterion is satisfied by the criteria in Subsection IV.1 of this appendix. The second criterion must be satisfied for SSE loads alone if Subsection IV.1 does not require an analysis for combined loads.	

4.0 GAIA DESIGN DESCRIPTION

4.1 *Fuel Assembly*

The GAIA fuel assembly comprises a 17x17 rod array specifically developed for use in Westinghouse-designed three and four loop nuclear reactors. The fuel assembly maintains the same interface compatibility and many of the features of previous AREVA fuel designs.

The GAIA fuel assembly incorporates eleven grids, twenty-four guide tubes, an instrument tube, and top and bottom nozzles to provide the structural cage for 264 fuel rods. The eleven spacer grids include six GAIA spacer grids axially distributed along the fuel assembly, three IGM grids placed between the GAIA spacer grids in the top of the active fuel region, and two HMP™ end spacer grids. The fuel rods are slightly raised off the bottom nozzle and are laterally supported by the six GAIA spacer grids and two HMP™ end spacer grids.

Twenty-four ¼-turn QD mechanisms are utilized to attach the top nozzle to the cage. The QD attachments at the top of each guide thimble allow the top nozzle to be removed remotely under water without the generation of loose parts and without the need for replacement parts.

Twenty-four self-capturing screws are utilized to attach the GRIP™ bottom nozzle to the cage. The attachments allow the bottom nozzle to be removed remotely under water without the generation of loose parts and without the need for replacement parts. Figure 4-1 and Table 4-1 highlight the fuel assembly design features.

4.2 *Fuel Rod*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR fuel rod design, consisting of uranium dioxide pellets, M5® cladding, zircaloy-4 end caps, and a nickel alloy plenum spring. Rods are pressurized with helium to provide good heat transfer, reduce clad creep-down, and restrict pellet to cladding interaction (PCI). This design is consistent with AREVA designs previously presented to the NRC in References 3 and 10.

The optimized chemical composition of the M5® alloy cladding and its refined microstructure provide enhanced resistance to corrosion and very low hydrogen uptake. This translates to less embrittlement, greater reliability at higher burnups, and anticipated compliance with future LOCA and RIA requirements.

The design utilizes a 144 inch fuel stack length of UO_2 or UO_2-Gd_2O_3 (Gadolinia) ceramic pellets, with a diameter of 0.3225 inch. There is a nominal 0.0065 inch diametric pellet to cladding clearance. The cylindrically shaped pellets are sintered to a nominal density up to [ ] Dished ends and geometric edge features ease the pellet loading into the cladding to prevent chipping, and also reduce the tendency of the pellet to assume an hourglass shape during operation. Pellet enrichments may be as high as 5.0 w/o U-235. The fuel stack may incorporate an axial blanket configuration at both ends, with enriched UO_2 or Gadolinia pellets in the central zone.

The zircaloy-4 upper and lower end caps have the same geometry. They have a bullet-nose feature to provide a smooth flow transition, in addition to facilitating rod insertion into the assembly, and a grippable top-hat shape that allows for removal from the fuel assembly in either direction. Upset-shape welds connect the end caps to the cladding. The nickel alloy spring is placed in the upper plenum, preventing the formation of fuel stack gaps during shipping and handling and allowing stack expansion during operation.

Figure 4-2 and Table 4-2 highlight the fuel rod design features.

4.3 *GAIA Spacer Grids*

The GAIA fuel assembly incorporates AREVA's new GAIA spacer grid design, which combines critical heat flux (CHF) performance, mechanical performance, fretting resistance, and low handling damage characteristics consistent with current AREVA PWR designs.

Constructed from M5® material, the individual strips are slotted and assembled in an egg-crate configuration and welded at each grid strip intersection. The trailing edge of the inner strips is equipped with mixing vanes. The outer strip precludes handling damage by incorporating a thicker strip, butt-welded corner joints inboard of the square envelope, and large lead-in tabs.

Spring hulls provide the interface with the fuel rods. They are inserted into the bottom of the grid and welded at the bottom strip intersections. [

] The spring hulls are oriented at 45 degrees to the strip, resulting in a spring in each cell corner that is vertically aligned with the fuel rod and emulates the 8-line contact area of AREVA's HTP™ and HMP™ product line. The 8-line contact area design has proven to be resistant to grid-to-rod fretting wear and has been previously approved by the NRC in Reference 11. It has been confirmed by comparative tests that the fretting behavior of the GAIA spacer grid rod support is consistent with the HTP™ spacer grid. The magnitude of the grid restraining force on the fuel rod is set high enough to ensure sufficient fuel rod support without overstressing the cladding at the points of contact or inducing excessive axial load on the fuel rod.

The GAIA spacer grid is connected to every guide tube and the instrumentation tube by [ ] In addition to maintaining the spacer grid axial positions, the weld connections help increase the fuel assembly lateral stiffness [ ] welds result in a high localized rotational stiffness and high overall cage lateral stiffness. The high overall cage lateral stiffness allows the fuel assembly to resist twist and bow, particularly at high burnups when spacer grid relaxation significantly reduces the coupling between the fuel rod and structural cage.

The GAIA spacer grid maintains adequate elastic strength to support external loads (i.e. seismic and LOCA), consistent with AREVA's current spacer grid designs. In addition, unlike other spacer grid designs, the GAIA spacer grid geometry remains stable after exceeding its elastic range due to the spring hull feature that provides localized reinforcement at each strip intersection. Under compressive dynamic loading, this stabilizing effect results in improved mechanical behavior which resists the large plastic deformation and loss of load-carrying capacity associated with a localized "buckling" failure mode. Instead, deformation of the spacer grid is uniformly distributed in each row as the [ ] With this "compressive" failure mode, geometric changes in the guide tube and fuel rod arrays remain relatively small. Under severe external dynamic loads, the GAIA spacer grid supports safe shutdown by maintaining the coolable geometry limits and providing a path for control rod insertion. The ability of the spacer grid to [ ] via uniformly distributed deformations, protects the core during severe postulated accident conditions.

Figure 4-3 through Figure 4-7 and Table 4-3 highlight the GAIA spacer grid design features.

4.4 *Intermediate GAIA Mixing Grid*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR Mid Span Mixing Grid (MSMG) design in the form of the IGM. The IGM is based on AREVA's Advanced MK-BW MSMG component, previously approved by the NRC in Reference 10. The IGM grids provide additional flow mixing in the high-heat flux region for improved DNB margin.

Constructed from M5®, the individual strips are slotted and assembled in an egg-crate configuration and welded at each strip intersection. To minimize the effect on bundle pressure drop, and to limit the additional material added within the active fuel region, the IGM grids are made from strips that are axially shorter than the GAIA spacer grids. The IGM has a smaller envelope than the adjacent GAIA spacer grids, which minimizes mechanical interaction with adjacent fuel assemblies.

Similar to the GAIA spacer grid, the trailing edge of the inner strips is equipped with mixing vanes ensuring efficient mixing. The mixing vane pattern of the IGM is consistent with the GAIA spacer grid.

Stops formed in each of the four cell walls prevent the fuel rods from contacting the mixing vanes, but impose no grip force (or slip load) onto the rods; thus, these are designated "non-contacting" spacer grids. The outer strip design precludes handling damage by incorporating a larger strip thickness (than the inner strips), wrap around corners which are inboard of the square envelope, and large leading and trailing edge lead-in tabs.

The IGM is connected to the guide tubes and instrumentation tube by resistance spot welding four weld tabs at each of the twenty-five locations on the top side of the spacer grid. In addition to maintaining the spacer grid axial positions, the mechanical weld connections help increase the fuel assembly lateral stiffness.

Figure 4-8 through Figure 4-10 and Table 4-4 highlight the IGM grid design features.

4.5 *HMP™ End Spacer Grids*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR HMP™ end spacer grid design.

Constructed from precipitation-hardened nickel alloy 718, the individual HMP™ doublet strips are slotted and assembled in an egg-crate configuration and welded at each strip intersection. Each doublet strip is made from two individual singlet strips tack welded together, forming a straight flow channel through the center of two opposing springs. The straight flow channel minimizes the hydraulic resistance of the spacer grid in locations outside of the active fuel region where flow mixing is not needed. The springs laterally preload and center the fuel rod within each cell, and create the grid-to-rod fretting resistant 8-line interface consistent with the fuel rod support previously approved by the NRC in Reference 11. The outer strip design precludes handling damage by incorporating lap welded corners which are inboard of the square envelope, and large leading and trailing edge lead-in tabs.

The nickel alloy 718 material provides high strength and reduced cell irradiation relaxation. The reduced cell relaxation, in combination with the 8-line interface, ensures that the HMP™ end spacer grid provides fuel rod lateral support and significant resistance against fretting wear throughout the design life.

One HMP™ end spacer grid is used at the bottom of the fuel assembly. This is of special importance in the lowermost region of the core where cross flows can be higher. One "relaxed" HMP™ end spacer grid is used at the top of the fuel assembly. The "relaxed" HMP™ end spacer grid has a reduced slip load compared to the bottom HMP™ end spacer grid. This is intended to reduce the fuel rod compressive forces due to axial fuel rod growth, and mitigate fuel rod bow concerns.

The HMP™ end spacer grids are axially restrained by means of sleeves, which are resistance spot welded directly to the guide tubes and instrument tube above and below the spacer grid.

Figure 4-11 through Figure 4-13 and Table 4-5 highlight the end spacer grid design features.

4.6 *Top Nozzle*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR top nozzle design, consistent with the AREVA design previously presented to the NRC in Reference 10.

The top nozzle consists of two high strength stainless steel bi-block frames, welded together to form a box-like structure. The upper structure provides for the interfaces with the reactor internals and the core components. The lower structure and grillage flow-hole pattern is designed to balance low pressure drop and strength requirements.

Four sets of leaf springs made of nickel alloy 718 are fastened to the nozzle with nickel alloy 718 clamp screws. During operation, the springs prevent fuel assembly lift due to hydraulic forces which ensures positive interaction with the upper and lower core internals. The upper leaf has an extended tang that engages a cutout in the top plate of the nozzle. This arrangement assures spring leaf retention in the unlikely event of a spring leaf or clamp screw failure.

The attachment of the top nozzle to the guide tubes consists of a ¼-turn QD assembly locking mechanism, which allows easy top nozzle removal and replacement. Removal and replacement requires only hand tools, has no loose parts, and does not require any replacement hardware. This contributes to a significant reduction in the amount of time required to perform fuel repairs and inspections. The locking mechanism is designed to rotate 90° in either direction to lock or unlock, and provides a positive indication when rotation is complete.

Figure 4-14 through Figure 4-15 highlight the top nozzle design features.

4.7 *GRIP™ Bottom Nozzle*

The GAIA fuel assembly incorporates AREVA's new GRIP™ bottom nozzle design, which combines high filter efficiency, high mechanical robustness, and low pressure drop characteristics consistent with current AREVA designs and incorporates new features for flow stabilization and protection against excessive rod vibration.

The GRIP™ bottom nozzle is made of three basic components. A one piece stainless steel machined frame with deep ribs provides the main structure. Four stainless steel feet are welded to the frame and provide the interface features for the lower core internals. A high strength stainless steel filter plate is fastened on the bottom face of the frame to provide high filtering efficiency, consistent with the AREVA design previously presented to the NRC in Reference 10.

Counter-bores in the top surface of the frame, and a leading edge bullet-nose feature in the middle of the frame, are designed to align with the fuel rod lower end caps. The fuel rod seats on the bottom of the counter-bore towards end of life, when the fuel assembly is most susceptible to grid-to-rod fretting. The seated fuel rod down in the counter-bore, in combination with the leading edge bullet nose, results in a streamlined flow through the nozzle which minimizes the lower region turbulence. When the lower end cap is encapsulated within the counter-bore, it protects against excessive fuel rod vibration that could be caused by flow anomalies in the lower region.

The GRIP™ bottom nozzle lower connection incorporates a new self-securing quick disconnect feature, allowing removal and replacement of the nozzle with no loose parts and no replacement hardware. The self-securing screws remain in the bottom nozzle during handling.

Figure 4-16 through Figure 4-19 highlight the bottom nozzle design features.

4.8 *MONOBLOC™ Guide Tube and Instrument Tube*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR MONOBLOC™ guide tube and instrument tube designs.

The MONOBLOC™ guide tube inner diameter at the top provides an annular clearance that permits rapid insertion of the rod cluster control assembly (RCCA) during a reactor trip. A reduced inner diameter in the dashpot region provides a closer fit with the control rods to decelerate the RCCA. This deceleration limits the RCCA impact loads on the top nozzle. Both inner diameters on the GAIA MONOBLOC™ guide tube are consistent with existing AREVA designs.

The MONOBLOC™ guide tube outer diameter is constant over the entire length, which results in additional material thickness and structural reinforcement in the dashpot region. The outer diameter of the GAIA MONOBLOC™ guide tube was increased to [ ] to improve the overall cage lateral stiffness. This provides additional resistance to twist and bow at high burnups, when spacer grid relaxation significantly reduces the coupling between the fuel rod and structural cage.

Four weep holes in the dashpot region allow coolant outflow during RCCA insertion and coolant inflow to control components during normal operation.

The MONOBLOC™ guide tube is constructed of a new quaternary alloy, Q12™ (Reference 5). Q12™ is an evolutionary development based on AREVA's M5® metallurgy, with low tin and iron added. Tin improves resistance to creep, with its content limited in order not to degrade the corrosion kinetics. Iron, in combination with niobium, is a key element for ensuring good corrosion performance. For structural components, these modifications provide higher irradiation creep strength without compromising the corrosion resistance. Q12™ is processed the same way as M5®, resulting in a fully recrystallized microstructure with fine grains and uniformly distributed precipitates.

The Q12™ instrument tube has a uniform inner and outer diameter. It is centrally located within the 17x17 array, extends the length of the fuel, and is fixed to the cage by resistance welds.

Figure 4-20 and Table 4-6 highlight the guide tube and instrument tube design features.

4.9 *Materials*

Table 4-7 summarizes the materials utilized on the GAIA fuel assembly design, identifying the alloys and the corresponding components.

Table 4-1 GAIA Fuel Assembly Parameters

Parameter	**Value**
Fuel Assembly Overall Length, inch	159.86
Fuel Assembly Envelope, inch	8.426
Fuel Rod Pitch, inch	0.496
Fuel Rods / Assembly	264
Guide Tubes / Assembly	24
Instrument Tubes / Assembly	1
Top Nozzle Type	Standard
Top Nozzle Attachment	¼-Turn QD
Bottom Nozzle Type	GRIP™
End Spacer Grid Type	HMP™ (qty 2)
Intermediate Spacer Grid Type	GAIA spacer grid (qty 6)
Intermediate Spacer Grid Attachment	[ ] at 25 locations
Mid Span Mixing Grid Type	IGM (qty 3)
Mid Span Mixing Grid Attachment	4 resistance welds (top) at 25 locations

Table 4-2 Fuel Rod Parameters

Parameter	Value
Cladding Material	M5®
Fuel Rod Length, inch	151.89
Pellet Stack Length, inch	144
Cladding Outer Diameter, inch	0.374
Cladding Thickness, inch	0.0225
Cladding Inner Diameter, inch	0.329
Clad-to-Pellet Gap, inch	0.0065
Fuel Pellet Outer Diameter, inch	0.3225
Plenum Springs	1 Top
Pellet Material	UO_2 and Gadolinia

Table 4-3 GAIA Spacer Grid Parameters

Parameter	Value
Material	M5®
Mixing Vanes	All 6 grids
Outer Strip Height, inch	[ ]
Outer Strip Thickness, inch	[ ]
Inner Strip Height, inch	[ ]
Inner Strip Thickness, inch	[ ]
Grid Envelope, inch	8.415
Nominal Cell Size, inch	[ ]

Table 4-4 IGM Grid Parameters

Parameter	Value
Material	M5®
Location	Top 3 intermediate spacer grid spans
Outer Strip Height, inch	[ ]
Outer Strip Thickness, inch	[ ]
Inner Strip Height, inch	[ ]
Inner Strip Thickness, inch	[ ]
Grid Envelope, inch	8.386
Nominal Cell Size, inch	[ ]

Table 4-5 HMP™ End Spacer Grid Parameters

Parameter	**Value**	
Material	Nickel Alloy 718	
Outer Strip Height, inch	[ ]	
Outer Strip Thickness, inch	[ ]	
Inner Strip Height, inch	[ ]	
Inner Strip Thickness, inch	[ ]	
Spacer Grid Envelope, inch	8.426	
Nominal Cell Size, inch	Top	Bottom
	[ ]	[ ]

Table 4-6 Guide Tube and Instrument Tube Parameters

Parameter	Value
Guide Tube and Instrument Tube Material	Q12™
Guide Tube Type	MONOBLOC™
Guide Tube and Instrument Tube Outer Diameter, inch	[ ]
Guide Tube Inner Diameter, inch	0.451 (top) 0.397 (bottom)
Instrument Tube Inner Diameter, inch	0.451
Guide Tube Wall Thickness, inch	[ ]
Instrument Tube Wall Thickness, inch	[ ]

Table 4-7 Summary of Component Materials

Material	Component
M5®	Fuel Rod Cladding
	IGM Grids
	GAIA Spacer Grids
Zircaloy-4	Quick Disconnect Sleeves
	Fuel Rod End Caps
	Guide Tube End Fitting
	Spacer Sleeves
Q12™	Guide Tube
	Instrument Tube
Stainless Steel	Top and Bottom Nozzle Structures
	Lower Connection Screw
	Holddown Spring Screw, Pin, Lockwire
	Bottom Nozzle Filter Plate, Fastening Pin, Washer
Nickel Alloy	HMP™ End Spacer Grids
	Lower Connection Locking Ring
	Holddown Springs
	Quick Disconnect Locking Spring, Ring, Lug
	Fuel Rod Plenum Spring
UO_2, Gadolinia	Fuel pellets

Figure 4-1 GAIA Fuel Assembly

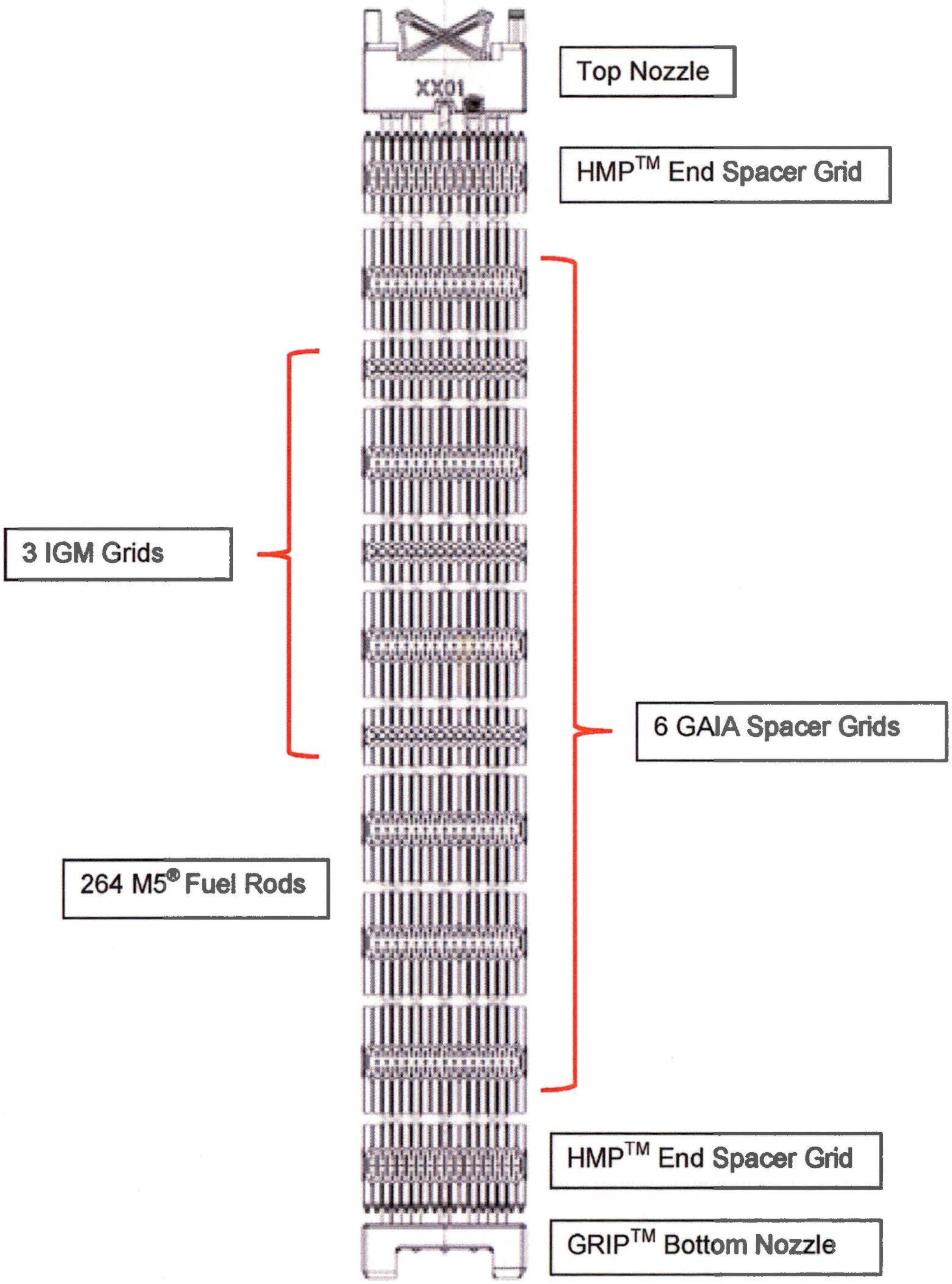


Figure 4-2 Fuel Rod Assembly

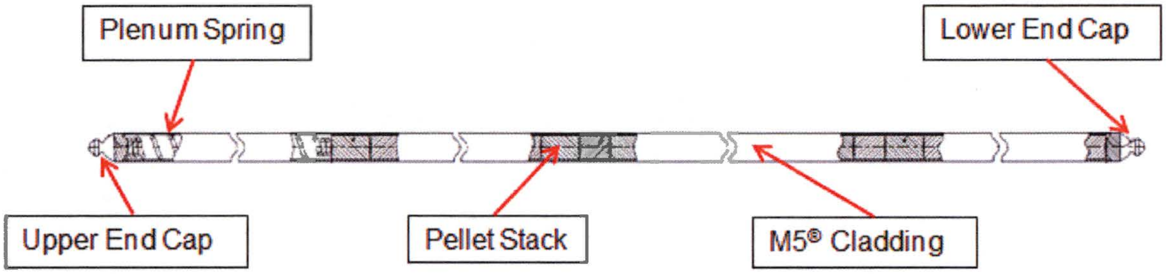


Figure 4-3 GAIA Spacer Grid

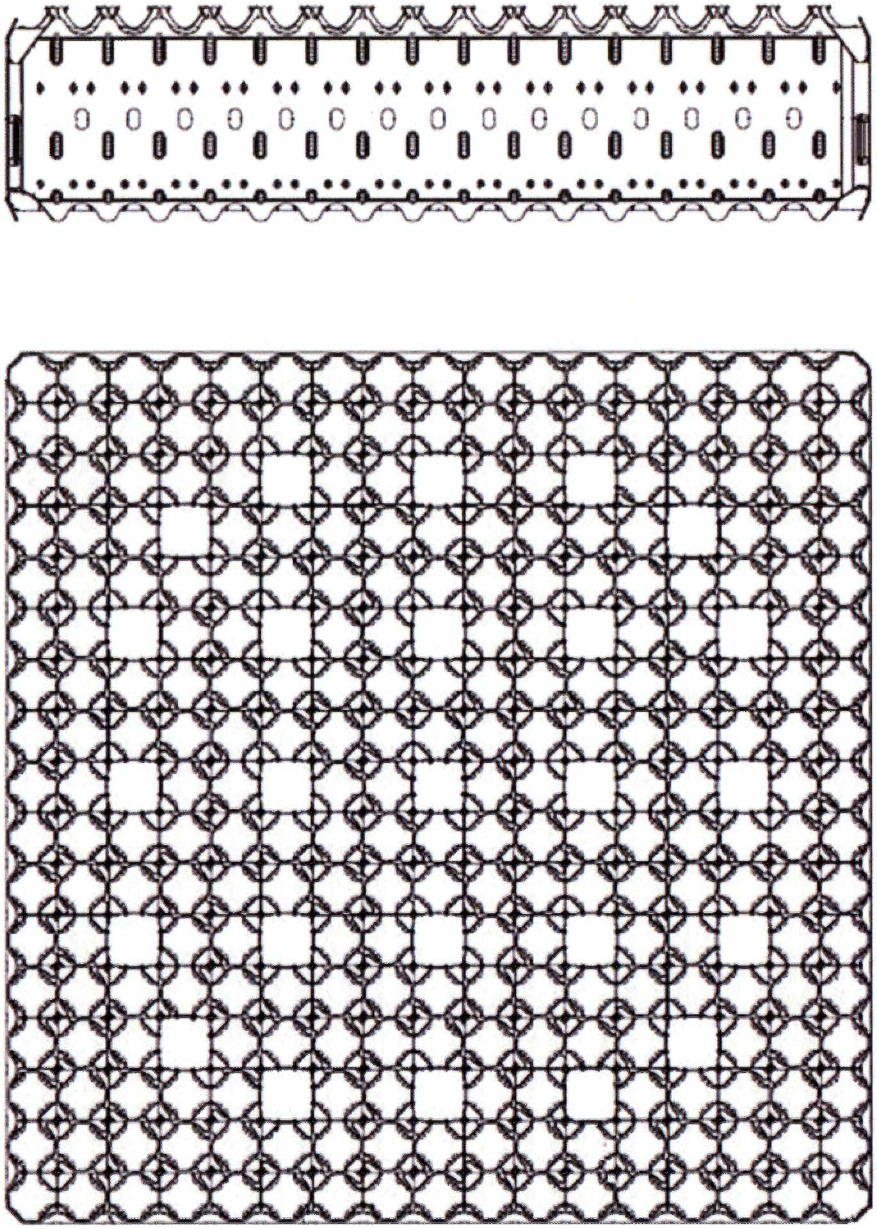


Figure 4-4 GAIA Spacer Grid – Inner/Outer Strip Features

[

]

Figure 4-5 GAIA Spacer Grid – Spring Hull Features

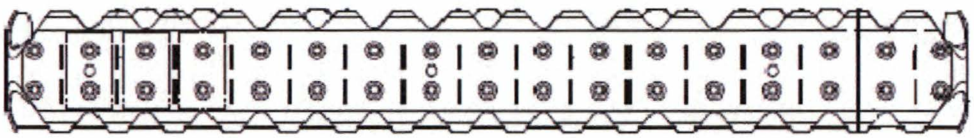
Figure 4-6 GAIA Spacer Grid Connection

Figure 4-7 GAIA Spacer Grid – Improved Mechanical Behavior

[

]

Figure 4-8 IGM Grid



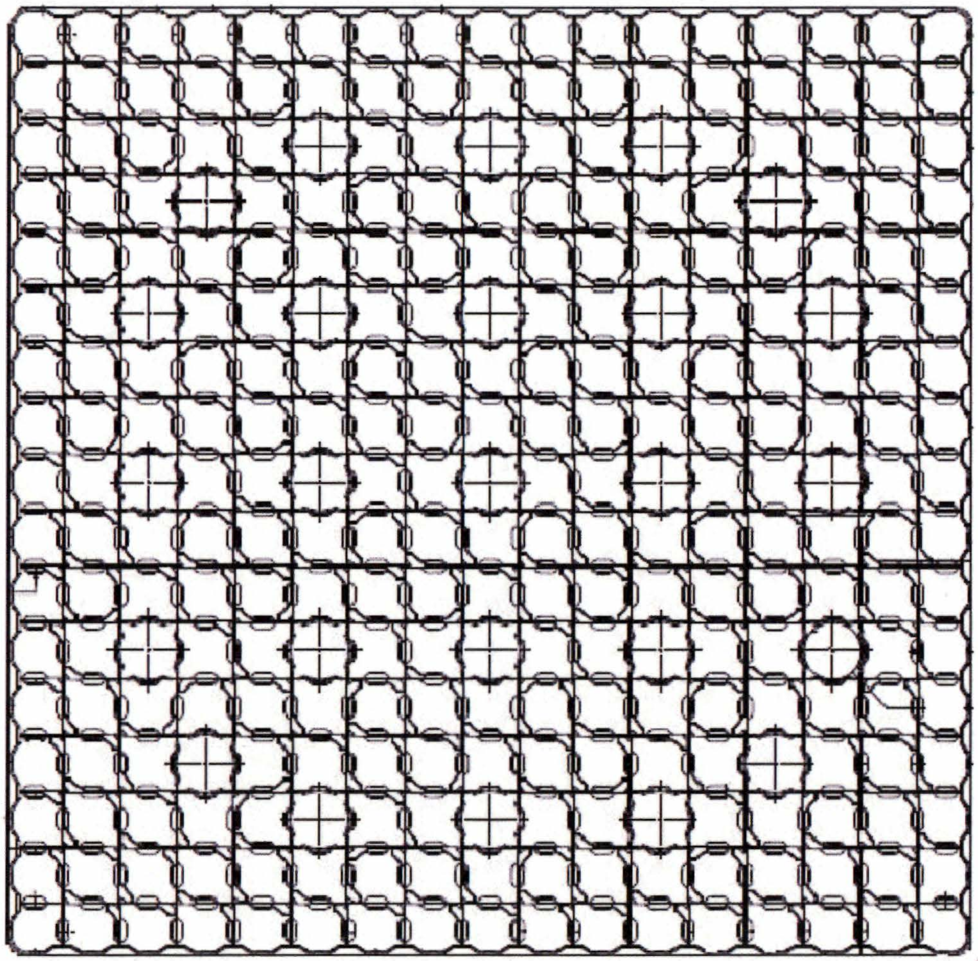


Figure 4-9 IGM Grid Features

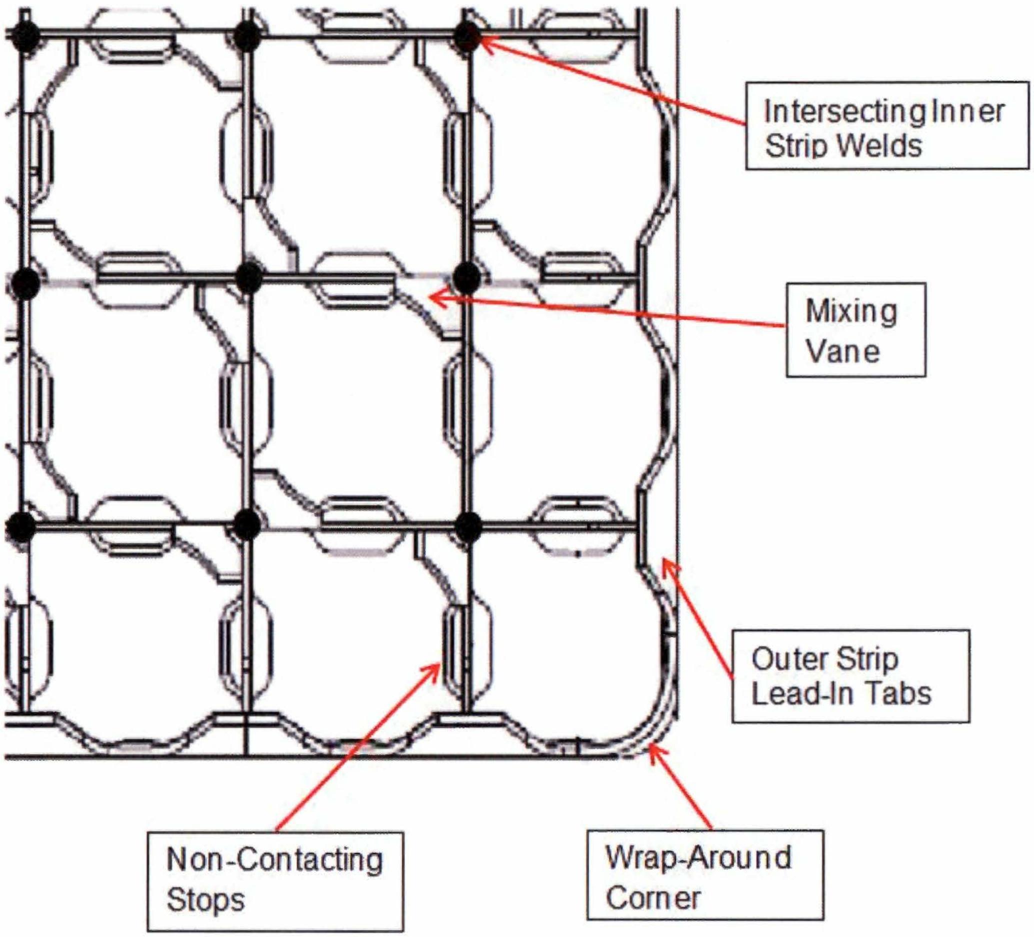


Figure 4-10 IGM Grid Connections

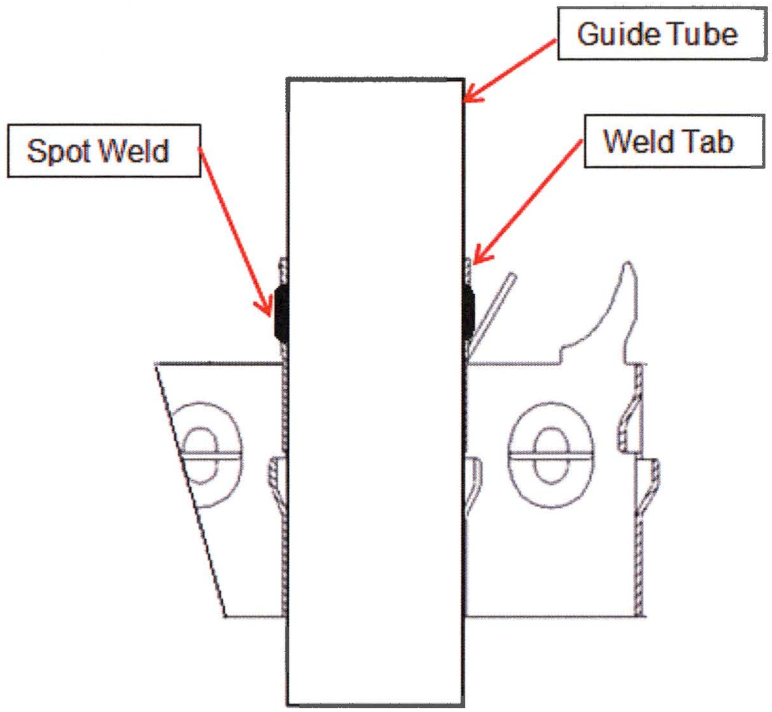
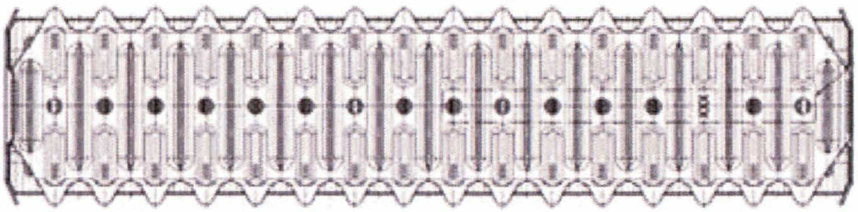


Figure 4-11 HMP™ End Spacer Grid



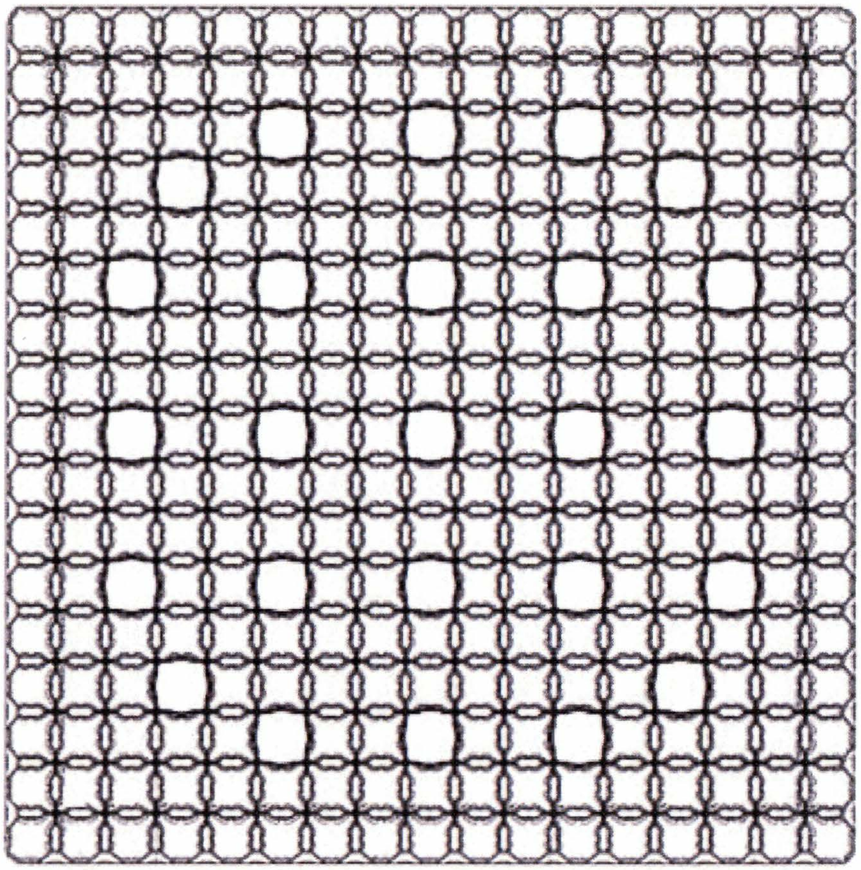


Figure 4-12 HMP™ End Spacer Grid Features

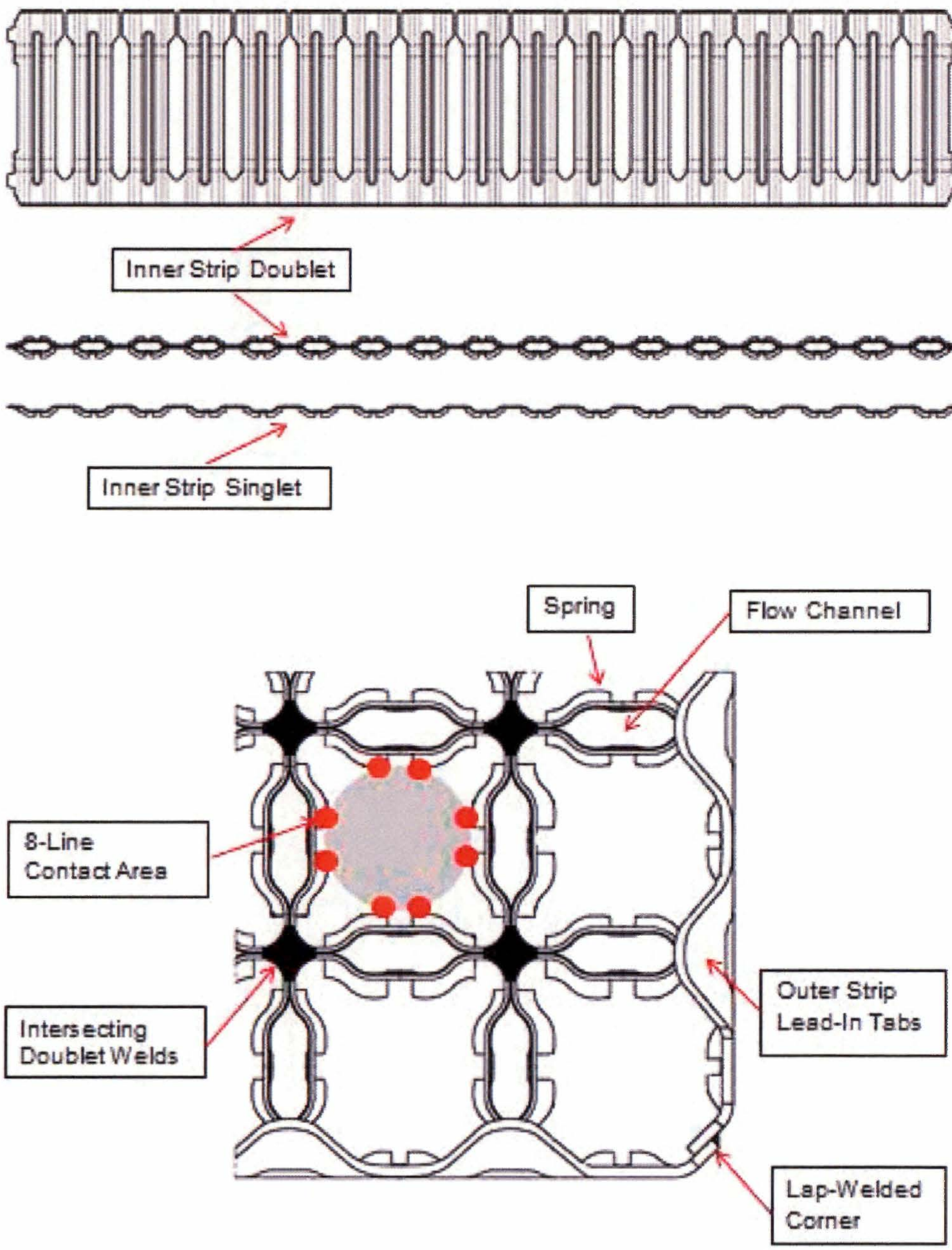


Figure 4-13 HMP™ End Spacer Grid Connection

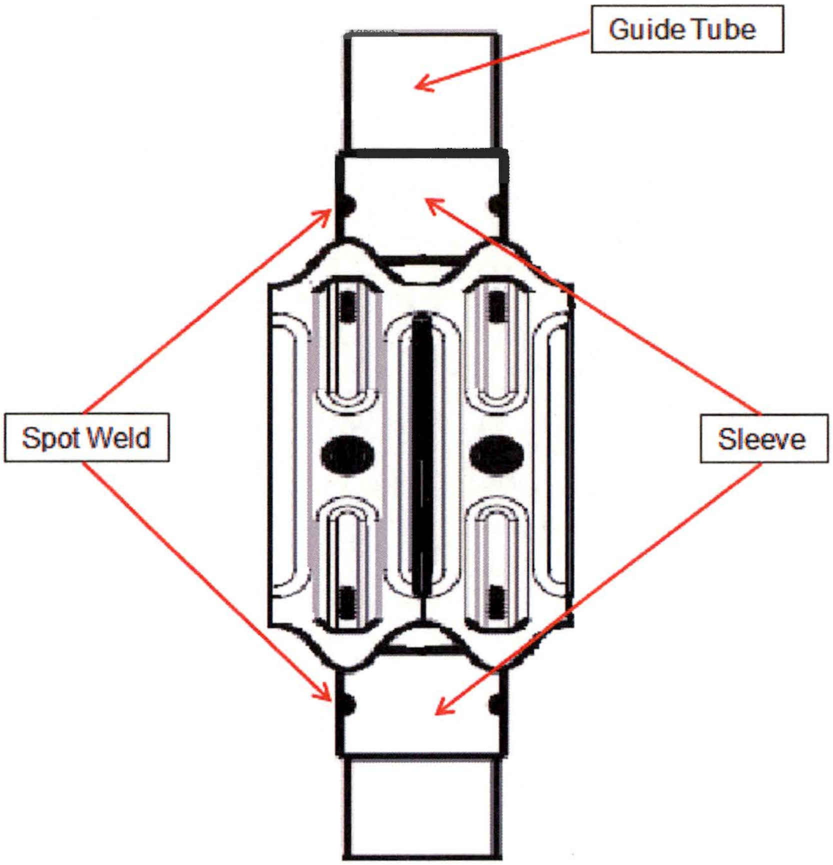


Figure 4-14 Top Nozzle

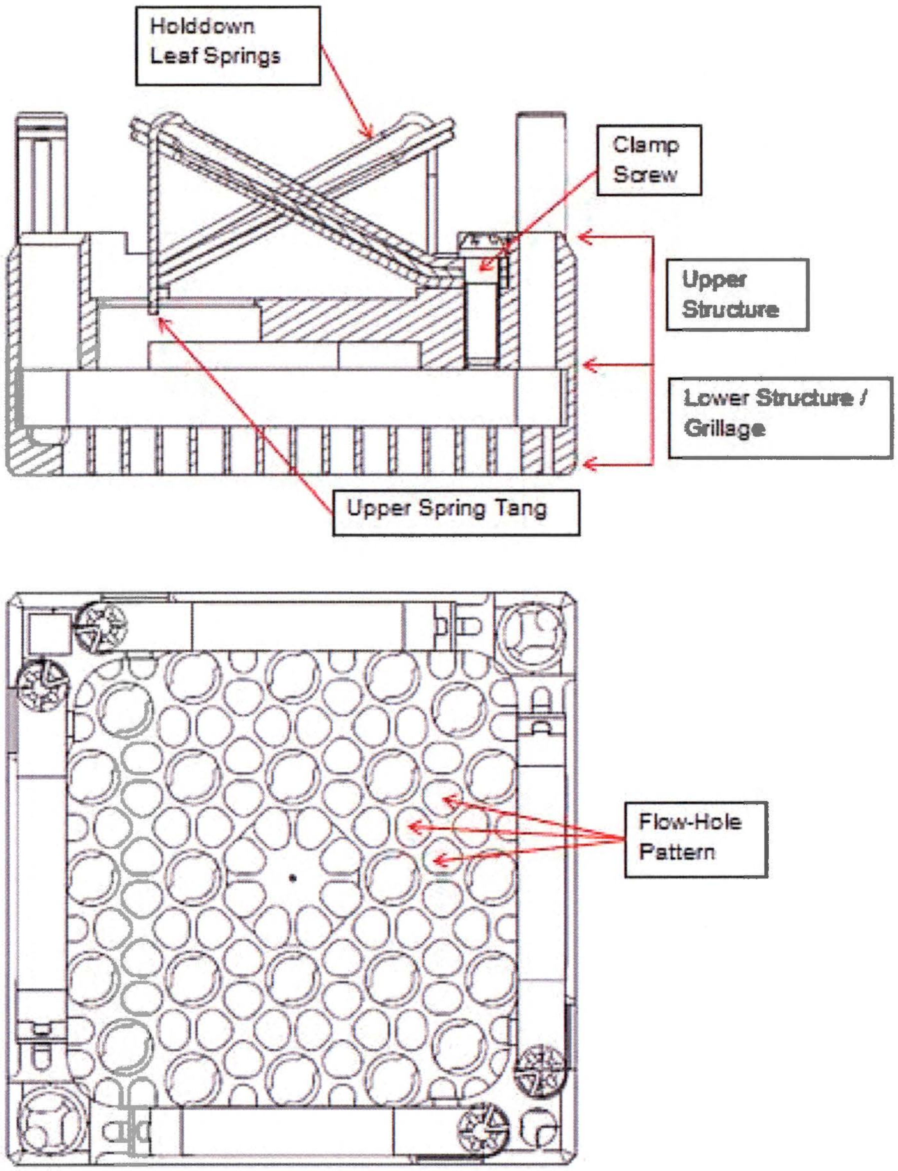


Figure 4-15 Top Nozzle 1/4-Turn QD

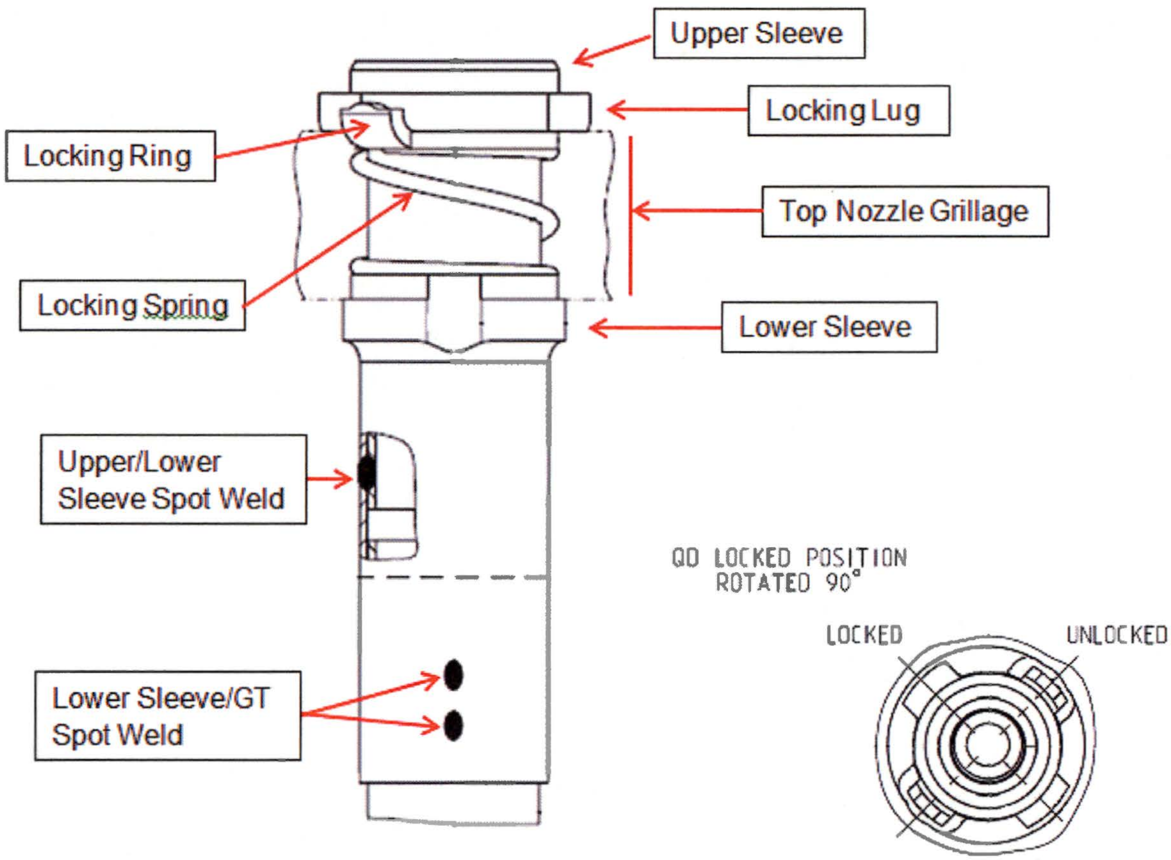


Figure 4-16 GRIP™ Bottom Nozzle

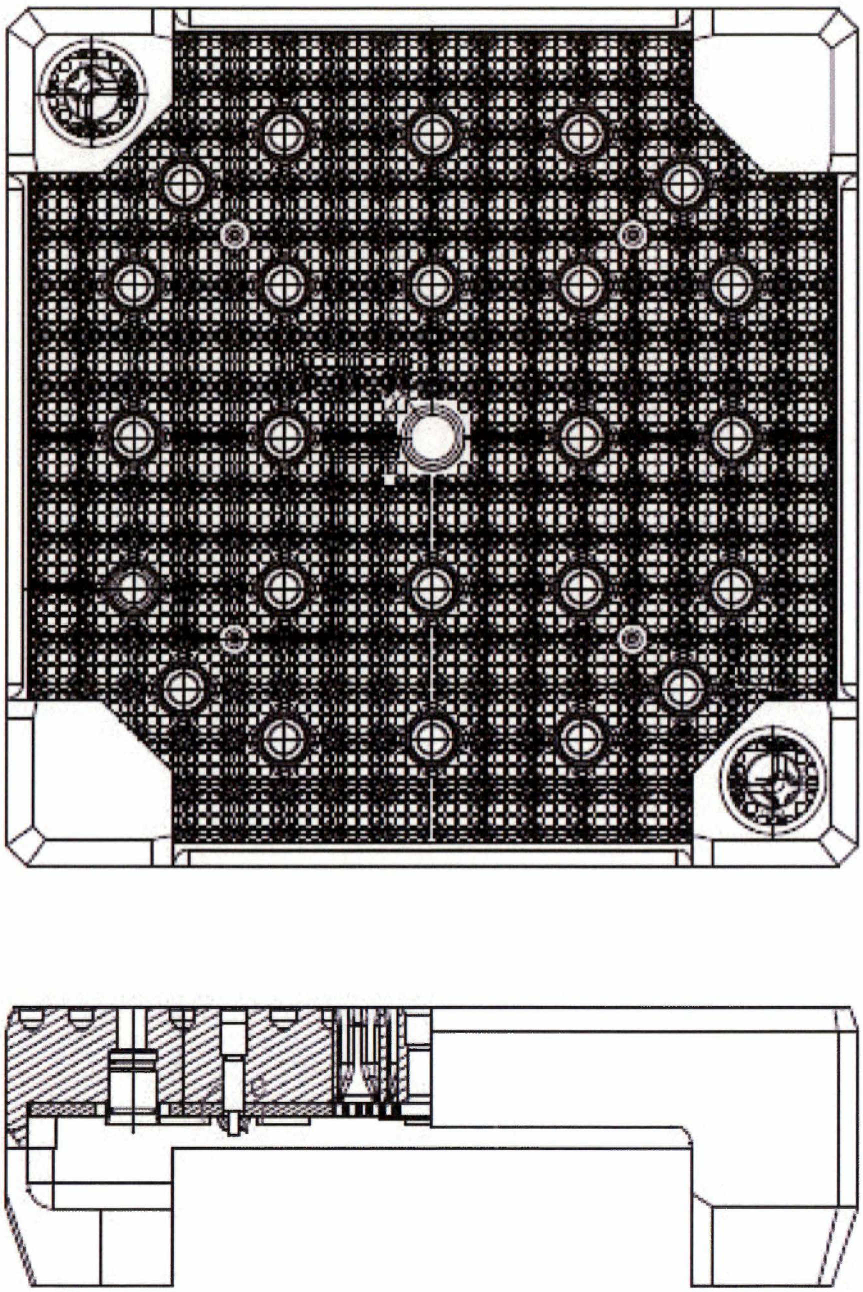
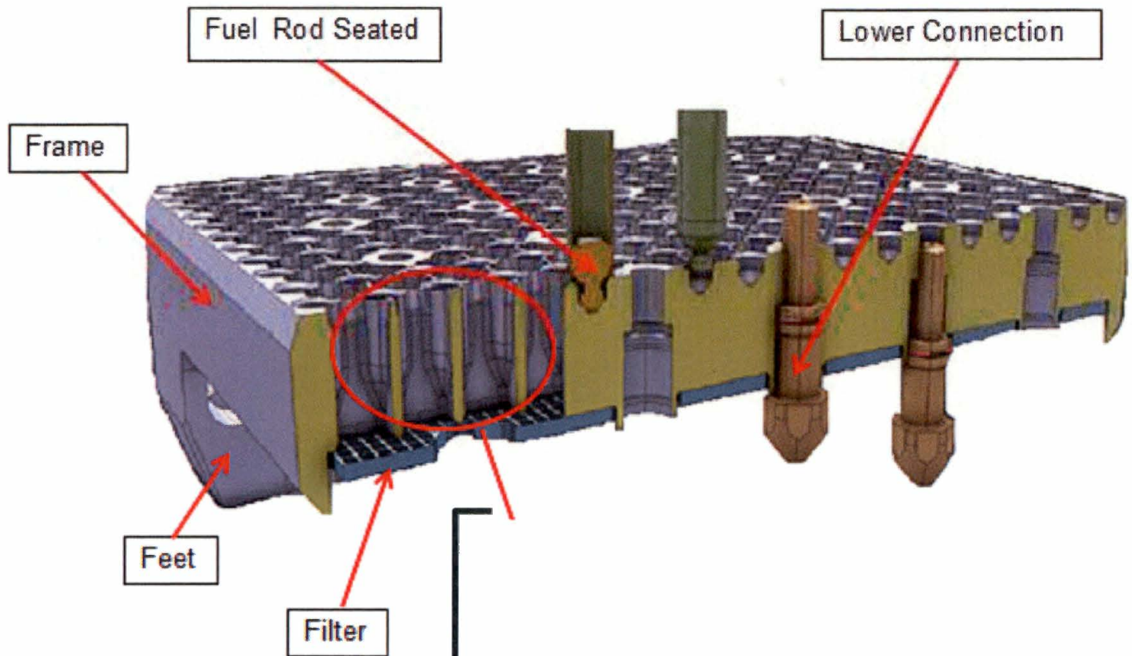


Figure 4-17 GRIP™ Bottom Nozzle Features

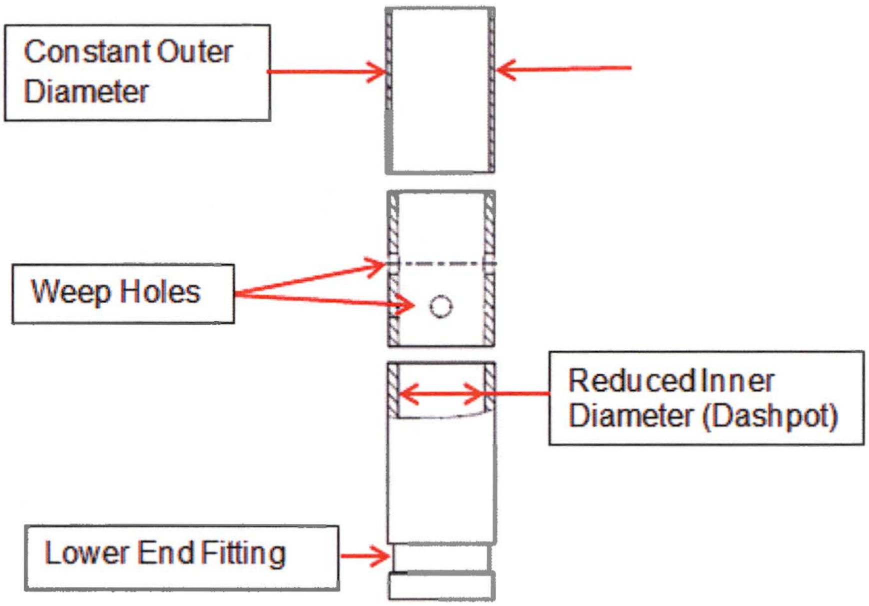


[ ]

Figure 4-18 GRIP™ Bottom Nozzle Filter

Figure 4-19 GRIP™ Bottom Nozzle Connection

Figure 4-20 MONOBLOC™ Guide Tube



5.0 GAIA FUEL ASSEMBLY TEST SCOPE

A comprehensive test program was conducted to characterize the performance of the GAIA fuel assembly design. Testing was conducted on full scale prototype fuel assemblies and on various assembly components.

5.1 *Fuel Assembly Mechanical Testing*

Fuel assembly mechanical tests included static axial tension and compression, static lateral bending, free and forced vibration, and vertical drop.

Testing was performed at AREVA's Technical Center located in Erlangen, Germany. These tests determined the overall static and dynamic mechanical characteristics of the fuel assembly, including axial and lateral stiffness, natural frequencies, damping, mode shapes, and component impact forces and speeds. Test results are used to benchmark horizontal and vertical analytical models for use in subsequent faulted analyses. Test components included [

] Testing was performed in air at room temperature.

5.2 *Fuel Assembly Thermal-Hydraulic Testing*

Fuel assembly thermal-hydraulic tests included pressure drop, life and wear, and flow induced vibration.

Pressure drop testing was performed at AREVA's HERMES-P flow loop, located in the CEA Centre of Cadarache, France. These tests determined the pressure loss coefficients of the components (spacer grids, inlet and outlet groups) and the rod bundle (for each span). Test results are used in fuel assembly analytical models, and as direct inputs to subsequent analyses. The pressure drop test component included a full scale assembly representing BOL conditions. The HERMES-P flow loop pressure drop tests are performed in water, with simulated in-core operating conditions including temperature, pressure, and axial flow. Additionally, an individual component pressure drop test determined the pressure loss coefficient of the IGM. This testing was performed at AREVA's MAGALY test loop located in Le Creusot, France. MAGALY flow loop pressure drop tests are performed in water, with simulated in-core operating conditions.

Life and wear testing was performed at the HERMES-P flow loop and AREVA's PHTF flow loop, located in Richland, Washington. These tests determined the fretting wear characteristics at the grid-to-rod interfaces. Wear shape and depth test results are used to support the fretting wear assessment. The life and wear test components included two full scale assemblies, both representing EOL conditions. Tests were run for 1000 hours in water, and included simulated operating conditions (temperature, pressure, and axial flow). In addition, the HERMES-P flow loop life and wear test includes simulated cross flows representing those that can be found at the lowermost span of the fuel assemblies in the reactor.

FIV testing was performed at AREVA's PETER flow loop, located in Erlangen, Germany. These tests verified that a fuel assembly self-induced excitation (SIE) does not exist and determined the fuel rod and fuel assembly flow-induced vibration (FIV) characteristics. SIE test results are used to support an overall fuel assembly flow stability assessment. [

] (discussed later). The SIE and FIV test component included one full scale assembly, representing [

] Tests are performed in water, with simulated in-core operating conditions including axial flow and cross flow.

5.3 *Component Mechanical and Testing*

Individual component mechanical tests included top nozzle, bottom nozzle, and upper connection tension and compression, holddown spring compression, bottom nozzle filter efficiency, spacer grid strength, and spacer grid fretting.

Top nozzle, bottom nozzle, and upper connection tension and compression tests determined the component axial stiffness and strength characteristics. Test results are used in fuel assembly analytical models, and as direct inputs to subsequent analyses. Test components are representative of production. Testing is performed in air at room temperature.

Top nozzle holddown spring compression tests determined the component force versus deflection characteristics. Test results are used in fuel assembly analytical models, and as direct inputs to subsequent analyses. Test components are representative of production. Testing is performed in air at room temperature.

Bottom nozzle filter efficiency tests determined the component filtering characteristics. Test results are used in an overall filter efficiency assessment. Test components and core plate interfaces are representative of production, and test debris is chosen based on operational feedback from the industry [

] Testing is performed in water at room temperature, with flow.

Spacer grid strength tests determined the component's overall strength characteristics, and include static compression, dynamic compression, edge handling, and corner strength. Test results are used in fuel assembly analytical models, and as direct inputs to subsequent analyses. Test components are representative of production.

[

]

Spacer grid fretting tests are conducted as a supplement to the 1000 hour life and wear testing, and determined the fretting wear characteristics at the grid-to-rod interfaces. Wear shape and depth test results are used to support the fretting wear assessment. Test components included 3 EOL GAIA spacer grid sections, with a fuel rod segment inserted, forming a 2-span test specimen. Testing was performed at AREVA's AUTOCLAVE facility located in Erlangen, Germany. Tests were run for 1500 hours [

] and the test rod is excited by an electro-magnetic system. Wear measurements are taken at multiple increments (e.g. 100 hours, 250 hours) in order to characterize the evolution of the wear depth and volume.

6.0 OPERATING EXPERIENCE

A summary of the relevant operating experience for the major components of the GAIA fuel assembly is provided in this section, including fuel rods, spacer grids, top nozzle, bottom nozzle, and guide tubes.

6.1 *Fuel Rods*

M5® fuel rod cladding was first inserted in a United States (U.S.) core in 1995. 22 U.S. reactors have used M5® alloy in more than 7500 fuel assemblies. Globally, more than 5 million M5® fuel rods have operated in more than 21,000 fuel assemblies in 84 reactors. The operational experience of M5® cladding covers fuel arrays from 14x14 up to 18x18.

6.2 *Spacer Grids*

A key feature of the GAIA spacer grid is the spring hull, which protects the fuel rod from fretting wear by providing an 8-line contact surface. The 8-line contact of the GAIA spring hull is based largely on the success of AREVA's HTP™ grid design, which was first inserted in a U.S. core in 1988. 20 U.S. reactors have used the HTP™ grid design in more than 8000 fuel assemblies. Globally, more than 18,000 HTP™ fuel assemblies have operated in 50 reactors. The operational experience of the HTP™ 8-line contact design covers fuel arrays from 14x14 up to 18x18.

Fuel assemblies with nickel alloy 718 HMP™ spacer grids were first inserted in core in 1998. Globally, more than 11,000 fuel assemblies equipped with an HMP™ grid design have operated in 42 reactors, including 19 U.S. reactors.

The IGM is based on AREVA's current non-contacting W17x17 MSMG design. Globally, more than 2300 fuel assemblies equipped with a non-contacting MSMG design have operated in 12 reactors, including 4 U.S. reactors.

6.3 *Top Nozzle*

The basic W17x17 top nozzle design was first inserted in core in 1996. Globally, more than 33,000 fuel assemblies equipped with the W17x17 top nozzle design have operated in over 70 reactors, including 6 U.S. plants.

6.4 *Bottom Nozzle*

A key feature of the GRIP™ bottom nozzle is the filter plate, which protects the fuel assembly from debris and debris fretting failures. The mesh filter plate of the GRIP™ bottom nozzle is based largely on AREVA's coarse mesh TRAPPER™ design which was first inserted in core in 1996. Globally, more than 33,000 fuel assemblies equipped with the TRAPPER™ filter plate design have operated in over 70 reactors, including 7 U.S. plants.

6.5 *Guide Tubes*

Fuel assemblies with MONOBLOC™ guide tubes were first inserted in core in 1998. Globally, more than 38,000 fuel assemblies equipped with the MONOBLOC™ guide tube design have operated in over 90 reactors, including 10 U.S. plants.

Q12™ guide tube material was first inserted in core in 2010. Globally, more than [ ] fuel assemblies equipped with Q12™ guide tube material have operated in [ ] reactors, including [ ]

7.0 LTA PROGRAMS

The GAIA program was a global design effort within AREVA's three main regions of operation (U.S., France, Germany), in cooperation with two customers to thoroughly test the design prior to batch implementation. Four GAIA LTAs were inserted in the core of an international reactor in 2012. Eight GAIA LTA's were inserted in the core of a U.S. reactor in 2015. Both plants are Westinghouse 3-loop designs.

7.1 *International Reactor LTA Program*

The four GAIA LTAs in the international reactor are consistent with the base GAIA description from section 4.0, [

]

The LTA's have successfully completed four (12-month) cycles with leaker-free performance to a fuel assembly burnup of [ ] GWd/MTU. Post irradiation examination (PIE) was performed after each cycle to evaluate the LTA performance. The in-core operation of the LTAs was as expected. A summary of the PIE scope is listed below.

- Visual examination
- Fuel assembly length and bow
- Spacer grid width and oxide
- Fuel rod length, diameter, bow, and oxide
- Lower connection torque and bottom nozzle removal assessment
- Fuel rod fretting assessment

Table 7-2 summarizes the LTA core operation history and Figure 7-1 provides core locations.

7.2 *U.S. Reactor LTA Program*

The eight LTAs in the U.S. reactor are consistent with the base GAIA description from section 4.0, as summarized in Table 7-3.

The LTA's have successfully completed one (18-month) cycle with leaker-free performance, with a fuel assembly burnup of [ ] GWd/MTU.

PIE's are planned at the end of each cycle to evaluate the LTA performance. A summary of the PIE scope is listed below.

- Visual examination
- Fuel assembly length, bow, and drag
- Spacer grid width
- Fuel rod length, bow, and oxide
- Fuel rod fretting assessment
- Guide tube oxide

Table 7-4 summarizes the LTA core operation history and Figure 7-2 provides the core locations.

Table 7-1 International Reactor GAIA LTA Design Summary

Table 7-2 International Reactor GAIA LTA Core Operation History

Table 7-3 U.S. Reactor GAIA LTA Design Summary

Fuel Assembly Component	GAIA Base Design (Section 4.0)	LTA Design
Top Nozzle	Standard, ¼-turn QD	Standard, ¼-turn QD
Bottom Nozzle	GRIP™	GRIP™
Fuel Rod Cladding	M5®	M5®
Bottom End Spacer Grid	HMP™	HMP™
Top End Spacer Grid	Relaxed HMP™	Relaxed HMP™
Guide Tube	Q12™ MONOBLOC™	Q12™ MONOBLOC™
Pellet	UO_2, Gadolinia, standard diameter	UO_2, Gadolinia, standard diameter
Intermediate Spacer Grid	GAIA spacer grid, [ ]	GAIA spacer grid, [ ]
Mid Span Mixing Grid	IGM	IGM

Table 7-4 U.S. Reactor GAIA LTA Core Operation History

[ ]

Figure 7-1 International Reactor GAIA LTA Core Positions

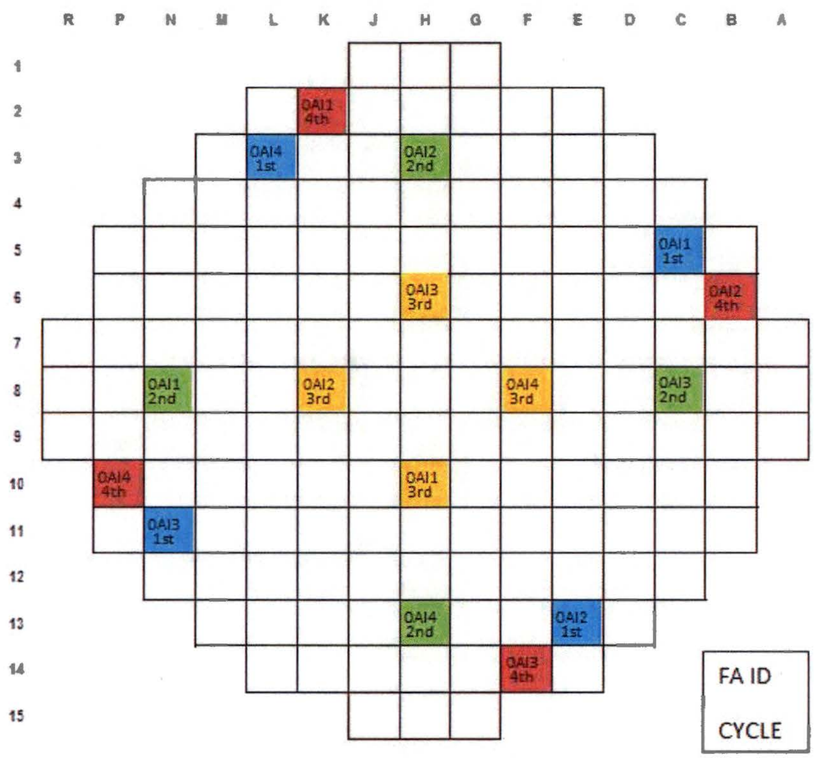
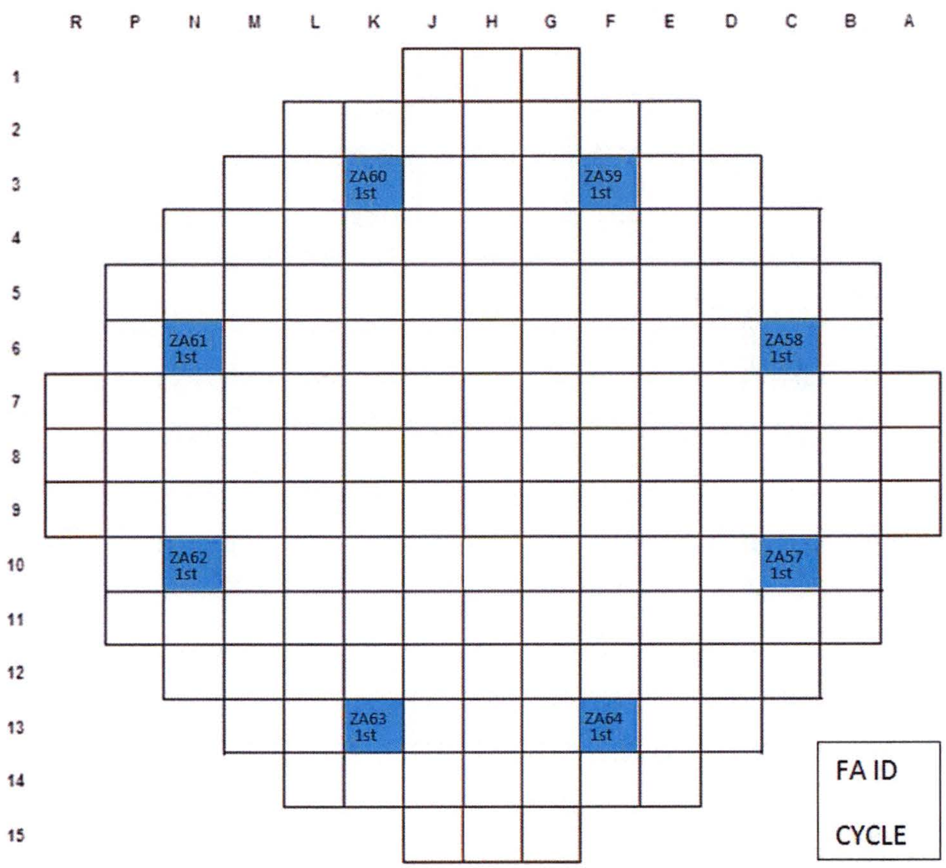


Figure 7-2 U.S. Reactor GAIA LTA Core Positions



8.0 DESIGN EVALUATIONS

The SAFDLs established to meet the relevant requirements of the NRC's regulations are provided in the following sections, consistent with the guidelines outlined in NUREG-0800 Chapter 4.2 (Reference 1). As delineated in section 3.0, SAFDLs are provided for fuel system damage, fuel rod failure, and fuel coolability as they relate to the mechanical performance of the fuel. Acceptance criteria associated with the other main areas in NUREG-0800 Chapter 4, including Nuclear Design section 4.3, Thermal and Hydraulic Design section 4.4, and Chapter 15, are not included as part of this topical report except as noted in Section 8.4.

The analyses demonstrate that the fuel assembly satisfies the mechanical requirements outlined in NUREG-0800 Chapter 4.2. The calculations are representative of fuel assembly operation in typical three- and four- loop Westinghouse-designed PWR 17x17 fuel plants. The analyses were performed for a peak UO_2 fuel rod burnup of 62 GWd/MTU and peak Gadolinia fuel rod burnup of 55 GWd/MTU. The impacts of coolant flow and temperature, operating power, fuel rod and assembly burnup, dimensional tolerances, irradiation and thermal relaxation, maldistribution, wear, and corrosion were considered.

8.1 *Fuel System Damage*

This subsection relates to the SAFDLs for normal operation, including AOOs as applicable, in addition to shipping and handling conditions. Fuel system damage criteria are included for all known damage mechanisms. Fuel damage criteria assure that fuel system dimensions remain within operational tolerances and that functional capabilities are not reduced below those assumed in the safety analyses. When applicable, the fuel damage criteria consider high burnup effects based on irradiated material properties data.

8.1.1 Stress, Strain, Loading Limits

Components are subjected to a multitude of loading conditions associated with normal operation, AOO's, shipping, and handling activities, which may lead to component failures.

8.1.1.1 Stress, Strain, Loading Limits Design Criteria

Stress and Load Limits:

Stresses and/or loads associated with normal operation, AOO's, shipping, and handling shall be less than limits based on Section III of the ASME Code (Reference 7) for all components, unless otherwise specified. This is in accordance with AREVA criterion previously approved by the NRC in References 8 and 9.

The specific criteria to be applied to the GAIA fuel assembly are shown below.

- Based on the ASME code, the basic component stress criteria (other than fuel rod cladding) are as follows.
  - Primary membrane stress intensity, Pm < Sm
  - Primary membrane plus bending stress intensity, Pm + Pb < 1.5 Sm
  - Primary and secondary membrane plus bending stress intensity, Pm + Pb + Q < 3Sm

    Where:

    Sm = min (1/3Su, 2/3Sy) at the applicable temperature
- The M5® fuel rod cladding stress criteria are [

]

- Consistent with the SRP guidance, component load criteria based on the ASME code is also used as an alternate for the component stress criteria defined above.

M5® Fuel Rod Cladding Strain:

Maximum uniform hoop strain (elastic plus plastic) shall not exceed 1%. This is in accordance with AREVA criterion previously approved by the NRC in Reference 2.

8.1.1.2 Stress, Strain, Loading Limits Methods

Stress and Load Limits:

AREVA uses conventional open-literature equations, in addition to general purpose finite element stress analysis codes (e.g. ANSYS), to calculate component stresses and/or loads associated with normal operation, AOO's, shipping, and handling. This is in accordance with AREVA methods previously approved by the NRC in References 3, 8, and 9.

In addition to assessment of the normal operating loads (including AOO's), the evaluation includes verification of an axial (compressive) shipping load equal to four times the weight of the fuel assembly (4g), a 6g lateral shipping load, and a 2.5g axial (tensile) handling load. The 4g axial and 6g lateral shipping loads are equal to AREVA's existing shipping container accelerometer limits.

Effects of corrosion on structural analyses are accounted for by a [

] Effects of fretting wear in AREVA designs are [

]

Additional details are provided below on a component basis.

- For the GRIP™ bottom nozzle normal operation assessment, loads from the fuel assembly weight, holddown spring system, and RCCA scram act on the bottom nozzle in compression at hot operating temperature. Upward lift from hydraulic flow is not credited. For the shipping and handling assessment, a 4g axial shipping load based on the fuel assembly dry weight acts on the bottom nozzle in compression at a slightly elevated shipping temperature. The 4g shipping load bounds the 2.5g handling load.
- For the top nozzle normal operation assessment, loads from the holddown spring and RCCA scram act on the top nozzle in compression at hot operating temperature. For the shipping and handling assessment, a 4g axial shipping load based on the fuel assembly dry weight acts on the top nozzle in compression at a slightly elevated shipping temperature. The 4g shipping load bounds the 2.5g handling load.
- For the guide tube normal operation assessment, loads from the fuel assembly weight, holddown spring system, hydraulic lift, and RCCA scram act on the guide tubes in compression and tension at a bounding hot operating temperature. Operating loads are evaluated on an individual guide tube span basis for primary and secondary membrane stresses and buckling. For the shipping and handling assessment, 4g axial and 6g lateral shipping loads based on the fuel assembly dry weight act on the guide tubes in compression, tension, and bending at a slightly elevated shipping temperature. The 4g axial shipping load bounds the 2.5g axial

handling load. Shipping and handling loads are evaluated on an individual guide tube span basis for primary and secondary membrane stress, bending stress, and buckling. Design limits for buckling are based on Euler and/or Timoshenko equations. Q12™ guide tube material properties are used per the applicable material specification, consistent with those in Reference 5.

- Structural connections are evaluated for a variety of loads for the normal operation and shipping and handling assessments, including those from the assembly weight, grid-to-rod slip loads, holddown spring, and RCCA scram. Calculations are performed at hot operating temperature, a slightly elevated shipping temperature, and room temperature for handling. Structural connection evaluations include weld joint shear strength (e.g. grid-to-guide tube, QD assembly-to-guide tube), lower connection stresses (e.g. membrane, thread shear), and QD component stresses (membrane, bearing).
- Grid evaluations are bounded by a 6g lateral shipping load. The maximum load is calculated at the longest grid span, and is taken as a proportional length fraction of 6 times the total fuel rod weight plus an additional clamping load. The strength of the grids under this mode of loading is conservatively derived from the 95% lower confidence level [ ] Future strength limits can be adjusted to reflect the actual shipping temperature.
- For the M5® fuel rod normal operation assessment, fuel rods are evaluated for steady state cladding stress and buckling. [

]

[ ]

Steady state cladding buckling is analyzed with the NRC-approved method in section 3.3 of Reference 3. [ ]

M5® Fuel Rod Transient Cladding Strain:

Transient cladding strain (TCS) is analyzed in accordance with the NRC-approved COPERNIC method in Reference 2. The COPERNIC code predicts the LHGRs where the onset of 1% TCS occurs. The cases are run with [ ] NRC-approved methods are used to demonstrate that the TCS criterion is satisfied.

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA TCS evaluations once applicability is demonstrated. The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.1.1.3 Stress, Strain, Loading Limits Evaluation

Stress, strain, and load limit calculations were performed for the GAIA structural components, including nozzles, guide tubes, structural connections, grids, and fuel rods. All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

Stress and Load Limits:

Detailed results are tabulated in Table 8-1, representing the limiting margins for the normal operation, shipping, and handling cases.

M5® Fuel Rod Cladding Strain:

Detailed results are tabulated in Table 8-2, representing the bounding TCS LHGR limits for each fuel rod type (UO_2, Gadolinia).

Holddown Spring Ultimate Strength:

The holddown spring system is evaluated for normal operating conditions to ensure it [ ] Satisfaction is demonstrated via testing, by verifying that the [ ] Maximum predicted spring deflections occur at cold conditions and are bounded by the tested deflection range. A [ ] does not impact the overall function of the holddown spring system and is accounted for in applicable analyses.

Test results verified that the GAIA holddown spring system maintained a [

]

8.1.2 Strain Fatigue

Cyclic loadings associated with relatively large changes in operating conditions can cause cumulative damage, which may lead to component fatigue failures.

8.1.2.1 Strain Fatigue Design Criteria

For all components other than fuel rod cladding, the CUF shall be less than 1.0. This criterion is in accordance with the ASME Code, Reference 7 (Section III, NG-3222.4). For M5® fuel rod cladding, the CUF shall be less than 0.9. This is in accordance with AREVA criterion previously approved by the NRC in Reference 3.

8.1.2.2 Strain Fatigue Design Method

AREVA uses the general methods prescribed in the ASME Code (Reference 7) to evaluate component fatigue stresses. This is in accordance with AREVA methods previously approved by the NRC in References 3, 8, and 9.

Fatigue performance is evaluated by determining the CUF based on the sum of the individual usage factors for each of the applicable recurring stress events. The O'Donnell Langer curves are used to estimate the corresponding number of allowed cycles of stress for each stress event and associated alternating stress. The design curves include a factor of safety of either 2 on stress or 20 on number of cycles, whichever is more conservative. The CUF is the number of expected cycles divided by the number of allowed cycles.

Specific to fuel rod cladding, the fatigue method is in accordance with section 3.6 of Reference 3. All representative Condition I and II transient events and one representative Condition III event were considered, equivalent to normal operation, AOO's, and postulated accidents respectively. The fuel rod is analyzed using a representative fraction of the number of transients the reactor pressure vessel will experience during its operation. Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fatigue evaluations once applicability is demonstrated. The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

Evaluation of guide tube fatigue is performed due to their significant load bearing function, in conjunction with their relatively thin walled construction. Guide tube fatigue usage is bounding for other similar components (e.g. ¼-turn QD sleeves). All repetitive loads are considered cyclic and the summation of all hot tensile and cold compressive stresses is determined for each guide tube span. The O'Donnell Langer curve for zirconium alloy material is used for Q12™ to estimate the corresponding number of allowed cycles of stress for each stress event and associated alternating stress.

Evaluation of holddown spring fatigue is performed by combining the usage factors based on normal operation and upset condition reactor coolant system design transients. The alternating stress is calculated by multiplying the strain range by [ ] in the ASME Code (section III, NG-3228), Reference 7.

8.1.2.3 Strain Fatigue Design Evaluation

Fatigue calculations were performed for the GAIA structural components, including fuel rods, guide tubes, and holddown springs. All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

A limiting fatigue CUF of [ ] was determined for the fuel rod cladding, which is less than the limit of 0.9.

A fatigue CUF of [ ] was determined for the guide tubes, which is less than the limit of 1.0.

A fatigue CUF of [ ] was determined for the holddown springs, which is less than the limit of 1.0.

8.1.3 Fretting Wear

Significant amounts of fretting wear can accumulate at fuel rod cladding contact points, which may lead to fuel rod fretting failures.

8.1.3.1 Fretting Wear Design Criteria

Fuel rod failures due to fretting shall not occur. This is in accordance with AREVA criterion previously approved by the NRC in References 8 and 9.

8.1.3.2 Fretting Wear Design Methods

Validation of the GAIA fuel rod fretting and wear performance was based on 1000 hour endurance flow testing. This is in accordance with AREVA methods previously approved by the NRC in References 8 and 9.

Testing was performed on full length fuel assemblies in AREVA's HERMES-P and PHTF flow test facilities. The test assemblies were modified to simulate EOL conditions. The GAIA spacer grids [ ] compared to a nominal fuel rod diameter of 0.374"). Testing was performed at representative core conditions, including; 590°F temperature, 2250 psi pressure, 17.26 ft/s axial flow rate, and a [ ] at the HERMES-P facility; and [ ] at the PHTF facility. Wear measurements were taken at 300, 700, and 1000 hour increments on the HERMES-P test assembly and after 1000 hours on the PHTF test assembly.

Based on the first of a kind nature of the GAIA fuel assembly design, two additional tests were conducted to supplement the 1000 hour life and wear test. PETER loop tests are used to evaluate SIE and FIV characteristics and AUTOCLAVE tests are used to validate grid fretting characteristics.

- PETER loop testing was performed on full length fuel assemblies. Components were [ ] (compared to a nominal fuel rod diameter of 0.374"). Testing was performed up to a [ ] in addition to representative core conditions including a variable axial flow rate of 12-21 ft/s and up to [ ] Testing includes the simulation of multiple operating conditions including adjacent nominal and c-shaped fuel assemblies, adjacent MSMG's, and seated fuel rods. Vibration measurements are recorded for the fuel rods and fuel assemblies at multiple locations for multiple axial flow rates.

- AUTOCLAVE testing was performed on a single fuel rod segment supported by three representative spacer grid segments. The test was performed in [ ] The fuel rod support conditions were [ ] The maximum root mean square vibrational amplitudes applied to the [ ] compared with the largest amplitude of less than 12 microns measured during the full scale PETER flow loop testing.

8.1.3.3 Fretting Wear Design Evaluation

1000 hour life and wear testing was successfully completed, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's. Supplemental testing verified the absence of fuel assembly SIE, low amplitude fuel rod FIV, and very low wear characteristics. All test results were as expected, with no wear abnormalities, and within the performance range of historical test results of proven in-reactor designs.

HERMES-P Flow Loop Life and Wear Test

A total of [ ] fuel rods were downloaded and inspected on the 1000 hour life and wear test assembly from the HERMES-P test flow loop, of which [ ] fuel rods were identified with measureable wear marks. Out of the [ ] fuel rod-to-spring interface locations inspected, a total of [ ] individual wear marks were identified and further examined. [ ] wear marks were located on the lower HMP™ end spacer grid and lowermost GAIA spacer grid, with another [ ] located on the MSMG's, and the remaining [ ] scattered amongst the top 6 grids. There were [ ] wear marks total with a depth greater than [ ] microns.

The average wear mark depths on the lower HMP™ end spacer grid and lowermost GAIA spacer grid were [ ] microns and [ ] microns, respectively, and the range of maximum wear mark depths on the MSMG's was [ ] microns. These values compare favorably to AREVA's proven fuel designs tested under similar conditions.

PHTF Flow Loop Life and Wear Test

A total of [ ] fuel rods were downloaded and inspected on the 1000 hour life and wear test assembly from the PHTF test flow loop, of which [ ] fuel rods were identified with measureable wear marks. Out of the [ ] fuel rod-to-spring interface locations inspected, a total of [ ] individual wear marks were identified and further examined.

There were [ ] wear marks total with a depth greater than [ ] microns. There were no wear marks greater than [ ] microns found on the GAIA spacer grids. The overall maximum wear depth measured was [ ] microns on an [ ] These values compare favorably to AREVA's proven fuel designs tested under similar conditions.

PETER Flow Loop Vibration Test

The supplemental PETER loop testing is used to assess the fuel assembly SIE. The largest vibrations were measured for the [ ] The maximum root mean square amplitude was less than 12 microns. The [ ] did not influence the overall fuel assembly vibration response. The low vibration amplitudes, over multiple test configurations, demonstrate that there are no SIE of the fuel assembly.

The supplemental PETER loop testing is also used to assess fuel rod FIV. The largest vibrations were measured for the simulated adjacent MSMG configuration at the maximum tested axial flow rate. Fuel rod FIV remained low, with a maximum amplitude less than 12 microns for all conditions.

AUTOCLAVE Wear Test

The supplemental AUTOCLAVE testing is used to assess the wear characteristics of the new GAIA spacer grid. A reference test was also performed with the W17 HTP™ spacer grid. The GAIA design was tested for 1500 hours and had a maximum wear depth of 20 microns, comparable to the results from the HTP™ reference test. The GAIA spacer grid wear depth and volume are very low and comparable to that of the HTP™, which has been shown through operating experience to be a robust design.

8.1.4 Oxidation, Hydriding, and Crud

Corrosion can reduce the material thickness resulting in a decrease in load carrying capability. Water-side corrosion can also facilitate hydrogen uptake, and high rates of hydriding can impact material ductility. Both hydriding and oxidation can exacerbate stress conditions which may lead to component failures.

M5® fuel rod cladding hydrogen uptake is controlled through application of corrosion limits. In addition, corrosion predictions are based on models developed from measurements representing typical combined crud and corrosion thicknesses and therefore inherently include the impacts of crud. Abnormal crud is addressed on a case specific basis if plant measurements indicate abnormal levels.

For components other than fuel rod cladding, the effects of oxidation and hydriding are minimized by the use of corrosion resistant materials that have been selected based on extensive AREVA and industry wide PWR reactor experience (e.g. zirconium-based alloys, stainless steels, nickel-based alloys). AREVA has characterized the oxidation and hydriding behavior of M5® spacer grids and Q12™ tube material, and results confirm good corrosion resistance and low hydrogen content with oxide thickness measurements under [ ] microns and hydrogen content measurements under [ ] ppm for fuel assembly burnups greater than [ ] GWd/MTU.

8.1.4.1 Oxidation, Hydriding, and Crud Design Criteria

Cladding peak oxide thickness shall not exceed a best-estimate predicted value of 100 microns. This is in accordance with AREVA criterion previously approved by the NRC in Reference 2.

8.1.4.2 Oxidation, Hydriding, and Crud Methods

The M5® peak cladding oxide thickness calculations are performed in accordance with the NRC-approved COPERNIC methodology in Reference 2. The analysis uses a

[

]

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fuel rod corrosion evaluations once applicability is demonstrated. The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.1.4.3 Oxidation, Hydriding, and Crud Evaluation

The predicted best estimate peak cladding oxide thickness is [ ] microns, which is less than the limit of 100 microns. This shows that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.1.5 Fuel Rod / Fuel Assembly Bow and Growth

Axial and lateral dimensional changes in the fuel rod and fuel assembly can occur due to irradiation growth, irradiation relaxation, creep, thermal expansion, etc. and can cause component to component or component to core interferences. These may lead to component failures and/or impacts on thermal hydraulic limits, control rod insertion, and/or handling damage.

There is no explicit design criterion for fuel assembly bow. AREVA uses operating experience and industry feedback to establish general design practices intended to minimize fuel assembly bow. GAIA components are designed to maximize cage lateral stiffness, minimize guide tube compressive stresses, and minimize guide tube creep. As an example, all three design practices are incorporated by the use of a larger diameter Q12™ MONOBLOC™ guide tube. Additional GAIA components which contribute to the overall resistance to fuel assembly bow include the use of IGM grids in the upper region of the fuel assembly (rigidly attached via 4 grid-to-guide tube welds), an [

] for each of the 6 GAIA spacer grids (high local rotational stiffness along the fuel assembly length), and a low pressure drop GRIP™ bottom nozzle (less axial holddown force required to prevent levitation).

AREVA has planned an extensive PIE scope for the irradiated GAIA LTA's, as documented in section 7.0. PIE programs continue to be an integral part in confirming the adequacy of the current and future GAIA fuel designs.

8.1.5.1 Fuel Rod / Fuel Assembly Bow and Growth Design Criteria

Fuel Rod Bow:

There is no explicit design criterion for fuel rod bow. Departure from nucleate boiling ratio (DNBR) and linear heat generating rate (LHGR) burnup thresholds and penalties are calculated and considered on a cycle by cycle basis to address the thermal-hydraulic limits established in SRP 4.4. This is in accordance with the AREVA approach previously approved by the NRC in Reference 12.

Fuel Rod and Fuel Assembly Growth:

Fuel rod irradiation growth is addressed by requiring clearance between the fuel rod and nozzles at EOL. Fuel assembly irradiation growth is addressed by requiring clearance between the fuel assembly and reactor core plates at EOL. This is in accordance with AREVA criteria previously approved by the NRC in References 8 and 9.

8.1.5.2 Fuel Rod / Fuel Assembly Bow and Growth Methods

Fuel Rod Bow:

DNBR and LHGR burnup thresholds and penalties are calculated in accordance with the NRC-approved method in Reference 12. The DNBR burnup thresholds are taken as the values at which at least a 50% fuel rod to fuel rod gap closure is predicted, which are the lowest burnups for which a penalty applies. The LHGR burnup thresholds are determined for the lowest burnup where the target LHGR penalty is exceeded.

Fuel Rod and Assembly Growth:

To assess fuel rod and fuel assembly growth, empirical models are used to compute the irradiation growth of the applicable components and the resulting changes are compared with the specified dimensions. This is in accordance with AREVA methods previously approved by the NRC in References 8 and 9.

The upper bound fuel rod growth and lower bound fuel assembly growth is used in conjunction with component manufacturing tolerances to determine the fuel rod shoulder gap margin. The upper bound fuel assembly growth is used in conjunction with component and core plate manufacturing tolerances to determine the fuel assembly gap margin. Limiting burnups and temperatures are considered.

The NRC-approved M5® fuel rod growth model in Reference 9 is used for the fuel rod growth bounds. The Q12™ guide tube growth model in Reference 5 is used for the fuel assembly growth bounds.

8.1.5.3 Fuel Rod / Fuel Assembly Bow and Growth Evaluation

Fuel Rod Bow:

DNBR and LHGR burnup thresholds are summarized in Table 8-3.

For burnup values below the DNBR and LHGR burnup thresholds, no penalty is applied. For burnup values past the DNBR burnup threshold, the DNBR penalty [

] No LHGR penalties were applied to the GAIA - IGM grid spans, since the exposure threshold is larger than 62 GWd/MTU. A sample of the LHGR penalties applied to the HMP™ – GAIA and GAIA – GAIA grid spans is provided in Table 8-4.

Fuel Rod and Assembly Growth:

A limiting fuel rod shoulder gap clearance of [ ] inch and fuel assembly core plate clearance of [ ] inch was determined at EOL , showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.1.6 Fuel Rod Internal Pressure

Excessive pin pressure can cause an increase in the fuel-to-clad gap due to cladding outward creep, which may lead to DNB propagation and component failures.

8.1.6.1 Fuel Rod Internal Pressure Design Criteria

Internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation or (2) reorientation of the hydrides in the radial direction in the cladding. This is in accordance with AREVA criteria previously approved by the NRC in Reference 2. The criteria for DNB propagation are included in other NRC-approved evaluation methods. DNB propagation is addressed as part of the plant-specific thermal hydraulic analyses.

8.1.6.2 Fuel Rod Internal Pressure Methods

The fuel rod normal operation internal pin pressure calculations are performed in accordance with the NRC-approved COPERNIC methodology in Reference 2.

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fuel rod pressure evaluations once applicability is demonstrated. The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.1.6.3 Fuel Rod Internal Pressure Evaluation

The limiting normal operation internal pin pressure was [ ] psia for a UO_2 rod, which is less than the allowable of [ ] psia. The clad to fuel strain rate was less than 1.0. The fuel rod internal pin pressure is acceptable to a design maximum burnup of 62 GWd/MTU for UO_2 rods and 55 GWd/MTU for Gadolinia rods, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.1.7 Fuel Assembly Lift-Off

Unseating a fuel assembly can change the fuel assembly lateral alignment, which can impact control rod insertion and subsequently lead to component failures.

8.1.7.1 Fuel Assembly Lift-Off Design Criteria

During normal operation conditions and AOO's (with the exception of a pump over-speed transient), the holddown springs shall maintain fuel assembly contact with the lower support plate. This is in accordance with AREVA criterion previously approved by the NRC in References 8 and 9.

Assuming a pump over-speed transient, fuel assembly lift-off can occur but the fuel assembly top and bottom nozzles shall maintain engagement with reactor internal pins and the holddown springs shall maintain positive holddown margin after the event.

8.1.7.2 Fuel Assembly Lift-Off Method

The fuel assembly lift-off methodology makes use of conventional open-literature equations to obtain a balance of forces on the fuel assembly in the vertical direction. This is in accordance with AREVA methods previously approved by the NRC in References 8 and 9.

The forces are due to fluid friction loss, buoyancy, momentum change, holddown spring force, and gravity. Forces due to friction losses are obtained through the use of loss coefficients derived from flow testing. Holddown forces are obtained from testing. Fuel assembly dry weight is measured or calculated. Other forces due to momentum and buoyancy are calculated based on the applicable fluid conditions. The evaluation includes the assessment of bounding operating conditions (including coolant temperatures and flowrates, mixed and homogeneous cores, BOL and EOL conditions), component dimensional characteristics (including reactor core plate to core plate and fuel assembly lengths, holddown spring deflections and mechanical set), and material characteristics (including thermal expansion, irradiation growth and relaxation, spring rate). The Q12™ guide tube growth model in Reference 5 is used to determine the fuel assembly growth bounds. Uncertainties are accounted for using a combination of deterministic and statistical methods.

Other NRC approved methods (e.g. Statistical Holddown, Reference 13), including the associated criteria and methods, may be utilized in the future for GAIA lift-off evaluations once applicability is demonstrated.

8.1.7.3 Fuel Assembly Lift-Off Evaluation

The analysis showed that the GAIA fuel assembly met all lift-off criteria, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's. The fuel assembly will not lift off under cold start-up and normal operating hot conditions, with a minimum margin-to-fuel assembly liftoff of [

]

8.2 *Fuel Rod Failure*

This subsection relates to SAFDLs for normal operation, AOO's, and postulated accidents. Fuel rod failure criteria are included for known fuel rod failure mechanisms. Adherence to the SAFDLs below ensures that fuel will not fail as a result of specific causes during normal operation and AOO's.

8.2.1 Hydriding

The absorption of hydrogen by the cladding internally can reduce material ductility and cause the formation of hydride platelets, which may lead to component failures.

8.2.1.1 Hydriding Design Criteria

Internal hydriding shall be precluded by appropriate manufacturing controls. This is in accordance with AREVA criterion previously approved by the NRC in References 8 and 9.

8.2.1.2 Hydriding Method

AREVA protects against this failure mechanism by imposing tight controls on hydrogen impurities during fuel rod fabrication and on the fuel rod components, including careful moisture control of the fuel pellets. This method is in accordance with AREVA methods previously approved by the NRC in References 8 and 9.

8.2.1.3 Hydriding Evaluation

The total fuel pellet hydrogen content, including moisture, is less than or equal to

[ ] showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.2.2 Cladding Collapse

If axial gaps in the fuel pellet column result from densification, the cladding has the potential to collapse into a gap (i.e. flattening). Because of the large local strains that accompany the collapsed (flattened) cladding, fuel rod cladding failure may occur.

8.2.2.1 Cladding Collapse Design Criteria

Predicted creep collapse life of the fuel rod must exceed the maximum expected in-core life. This is in accordance with AREVA criterion previously approved by the NRC in Reference 4.

8.2.2.2 Cladding Collapse Method

The M5® cladding collapse calculations are performed in accordance with NRC-approved methods, COPERNIC in Reference 2 and CROV in Reference 4. Reference 3 extends the applicability of the CROV method to M5® material. COPERNIC is used to simulate the performance of the fuel rod throughout its lifetime and is used as input to initialize the CROV code. The output parameters which CROV takes from the COPERNIC simulation are [ ] The COPERNIC outputs along with the fuel rod geometry [ ] are then used by the CROV code in a simulation of the cladding creep-down deformations versus time of exposure of the rod. The code outputs the rod diameter and ovality at each time step. When the ovality creep rate of the cladding exceeds [ ] or the generalized stress within the cladding exceeds generalized yield strength, then the cladding is considered to have failed. In addition, the bifurcation buckling pressure must not be exceeded at time zero.

8.2.2.3 Cladding Collapse Evaluation

The fuel rod creep collapse lifetime was shown to be greater than the design burn-up of 62 GWd/MTU for UO_2 rods and 55 GWd/MTU for Gadolinia rods, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's. The maximum deformation rate is approximately [ ] which is less than the limit of [0.1 mil/hour.] The maximum predicted general cladding stress is [ ] psi, which is less than the generalized cladding yield strength limit of [ ] psi during the rod lifetime. The maximum differential pressure at time zero is [ ] psi, which is less than the bifurcation buckling pressure limit of [ ] psi.

8.2.3 Overheating of Fuel Pellets

If there is CFM and subsequent axial or radial relocation of the molten fuel, there is a potential for contact with the cladding or the formation of local hot spots. Because of the overheating that accompanies these conditions, fuel rod cladding failure may occur.

8.2.3.1 Overheating of Fuel Pellets Design Criteria

Fuel melting during normal operation and AOO's is precluded. This is in accordance with AREVA criterion previously approved by the NRC in Reference 2.

8.2.3.2 Overheating of Fuel Pellets Method

CFM is analyzed in accordance with the NRC-approved COPERNIC method in Reference 2. The COPERNIC code predicts the LHGRs where the onset of CFM occurs. The cases are run with power history envelopes up to various exposures and then the rods are ramped to the power where the fuel melt occurs using a normalized axial power distribution. NRC-approved methods are used to demonstrate that the CFM criterion is satisfied.

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA CFM evaluations once applicability is demonstrated. The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.2.3.3 Overheating of Fuel Pellets Evaluation

Detailed results are tabulated in Table 8-5, representing the bounding CFM LHGR limits for each fuel rod type (UO_2, Gadolinia).

8.3 *Fuel Coolability*

This subsection applies to postulated accidents, specifically their potential impact on control rod insertability and core coolability due to component gross structural deformations.

8.3.1 Structural Deformation

Earthquakes and postulated pipe breaks in the reactor coolant system result in external forces on the fuel assembly. The fuel assembly is designed to withstand these loads from OBE, SSE, and LOCA events without loss of the capability to perform the safety functions that are commensurate with these events.

8.3.1.1 Structural Deformation Design Criteria

OBE, SSE, and LOCA stress and/or load limit criteria are in accordance with section 4 of the PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations topical report (Reference 6). The analyzed events are categorized by different severity levels. OBE stress and load limits are set at the level A limits defined in the ASME Code, unless otherwise specified. SSE and LOCA stress and load limits are set at the Level D limits defined in the ASME Code, unless otherwise specified. Due to their special functions (i.e. forming a path for control rod insertion, ensuring coolable geometry is maintained, protecting the fission product barrier), spacer grids, guide tubes, and fuel rods are subject to more stringent service limits including;

OBE Spacer Grid Acceptance Criteria

Spacer grid deformation experienced during an OBE event should not exceed the magnitude of the tolerance band to which the grid was designed. This acceptance criterion is established in the form of a grid impact load limit, which corresponds to a small amount of plastic deformation in the spacer grid that is within the envelope tolerance and does not exceed the deformation at the buckling point of the grid.

SSE/LOCA Spacer Grid Acceptance Criteria

Spacer grid deformation experienced during an SSE/LOCA event [

]

SSE/LOCA Fuel Rod Acceptance Criteria

Fuel rods must be protected against mechanical fracturing. M5® fuel rod cladding stress criteria are in accordance with those defined in section 8.1.1.1.

SSE/LOCA Guide Tube Acceptance Criteria

Sudden and severe changes in the geometry of the guide tube (e.g. local collapse or plastic hinge) shall not occur. This acceptance criterion is further delineated by requiring that (1) stresses do not exceed a limit prohibiting local collapse of the guide tube, and (2) the structural stability of the guide tube must be maintained. The first criterion is met by limiting guide tube stresses to the Level C criteria in accordance with the ASME Code. The second criterion is satisfied by evaluating the critical buckling load margin.

8.3.1.2 Structural Deformation Method

The component OBE, SSE, and LOCA stress and/or load limit calculations are performed in accordance with section 8 of the PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations methodology (Reference 6). The analysis is performed independently in the horizontal and vertical directions using numerical models developed to simulate the mechanical behavior of fuel assemblies. These models capture the motion of the fuel due to the event and the interaction between neighboring fuel assemblies and the baffle as applicable. Results from the horizontal and vertical analyses are used to calculate the maximum design impact loads and stresses which are then compared against the allowable values for each structural component.

8.3.1.3 Structural Deformation Evaluation

All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all postulated accident conditions and AOO's. Detailed results are tabulated in Table 8-6, representing the limiting margin for the OBE, SSE, and SSE+LOCA loading events.

8.4 *Additional Acceptance Criteria*

This subsection identifies SAFDLs that are not evaluated as part of this topical report. These additional SAFDLs address the remaining fuel design criteria from SRP Section 4.2 and any pertinent criteria from SRP Sections 4.3 and 4.4 that are not covered by the SRP Section 4.2 criteria (Section 8.4.7). With the inclusion of these criteria, this topical report presents a complete set of SAFDLs to be used for evaluation of the GAIA fuel assembly design.

8.4.1 Overheating of Cladding

The criteria for departure from nucleate boiling are included in the NRC-approved critical heat flux (CHF) correlation topical report for use with the GAIA fuel assembly.

Departure from nucleate boiling is addressed in plant-specific thermal hydraulic analyses using NRC-approved methods, including approved mixed core methods. The ORFEO-GAIA and ORFEO-NMGRID correlations are applied to the GAIA fuel assembly as described in Reference 14.

8.4.2 Excessive Fuel Enthalpy

The criteria for excessive fuel enthalpy during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

Reactivity initiated accidents are addressed in plant-specific analyses using NRC-approved methods.

8.4.3 Bursting

Cladding swelling and rupture requirements are included in the NRC-approved loss-of-coolant accident (LOCA) evaluation models.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.4 Cladding Embrittlement

The criteria for cladding embrittlement during a LOCA are included in the NRC-approved LOCA evaluation methods.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.5 Violent Expulsion of Fuel

The criteria for violent expulsion of fuel during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

Reactivity initiated accidents are addressed in plant-specific analyses using NRC-approved methods.

8.4.6 Fuel Rod Ballooning

Fuel rod ballooning requirements are included in the NRC-approved LOCA methods.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.7 Reactivity Coefficients

The Doppler coefficient shall be negative at all operating conditions. The power coefficient shall be negative at all operating power levels relative to hot zero power.

Nuclear design criteria are addressed in plant-specific analyses using NRC-approved methods.

8.5 *Design Evaluation Summary*

The GAIA fuel assembly was shown to meet all SAFDLs for UO_2 fuel rod burnups up to 62 GWd/MTU and Gadolinia fuel rod burnups up to 55 GWd/MTU. The GAIA design incorporates multiple features that are based on existing AREVA designs with reactor-proven operating experience. This operating experience, coupled with the design verification testing and analyses that demonstrate the acceptability of GAIA's added design features, ensures that the GAIA fuel assembly will operate safely and reliably.

Table 8-1 Stress, Strain, Loading Limits Design Margin Summary

Table 8-2 TCS LHGR Limits Summary

[ ]

Table 8-3 Rod Bow Burnup Threshold Summary

[ ]

Table 8-4 Grid Span LHGR Penalty Summary

[ ]

Table 8-5 CFM LHGR Limits Summary

[ ]

Table 8-6 Faulted Stress, Loading Limits Design Margin Summary

9.0 REFERENCES

1. Standard Review Plan, Section 4.2, NUREG-0800 Revision 3, U.S. Nuclear Regulatory Commission, March 2007

2. BAW-10231P-A, Revision 1, COPERNIC Fuel Rod Design Computer Code, January 2004

3. BAW-10227P-A, Revision 1, Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, June 2003

4. BAW-10084P-A, Revision 3, Program to Determine In-Reactor Performance of BWFC Fuel Cladding Creep Collapse, July 1995

5. ANP-10334P-A, Revision 0, Q12™ Structural Material, September 2017

6. ANP-10337P-A, Revision 0, PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations, April 2018

7. American Society of Mechanical Engineers, *Boiler and Pressure Vessel Code*, Section III, Nuclear Power Plant Components, 1992 Edition

8. EMF-92-116P-A, Revision 0, Generic Mechanical Design Criteria for PWR Fuel Designs, February 1999

9. BAW-10240P-A, Revision 0, Incorporation of M5™ Properties in Framatome ANP Approved Methods, May 2004

10. BAW-10239P-A, Revision 0, Advanced Mark-BW Fuel Assembly Mechanical Design Topical Report, July 2004

11. ANF-89-060A and Supplement 1, Generic Mechanical Design Report High Thermal Performance Spacer and Intermediate Flow Mixer, May 1991

12. XN-75-32P-A, Supplements 1, 2, 3, & 4, Computational Procedure for Evaluating Fuel Rod Bowing, October 1983

13. BAW-10243P-A, Statistical Fuel Assembly Holddown Methodology, September 2005

14. ANP-10341P-A, Revision 0, The ORFEO-GAIA and ORFEO-NMGRID Critical Heat Flux Correlations, September 2018

CORRESPONDENCE

- NRC-16-038
- NRC-18-044
    - ANP-10342Q1P
- NRC-19-023

AREVA

December 21, 2016
NRC:16:038

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Request for Review and Approval of ANP-10342P, "GAIA Fuel Assembly Mechanical Design"

AREVA Inc. (AREVA) requests NRC review and approval of topical report ANP-10342P, "GAIA Fuel Assembly Mechanical Design" for referencing in licensing actions. This report describes the GAIA fuel assembly mechanical design intended for use in pressurized water reactors and contains a generic evaluation of the fuel assembly mechanical performance.

In support of the Office of Nuclear Reactor Regulation's prioritization efforts, the topical report prioritization scheme is included as an enclosure with this letter. AREVA would appreciate NRC approval of this topical report by December 2018 to support licensee submittals.

AREVA considers some of the material contained in ANP-10342P to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support withholding of information from public disclosure. A proprietary version and a non-proprietary version of the topical report are enclosed.

This correspondence contains no new regulatory commitments.

If you have any questions related to this submittal, please contact Mr. Nathan Hottle, (Product Licensing Manager) by telephone at (434) 832-3864, or by e-mail at Nathan.Hottle@areva.com.

Sincerely,

Gary Peters, Director
Licensing & Regulatory Affairs
AREVA Inc.

cc: J. G. Rowley
Project 728

Enclosures:

1. ANP-10342P Rev. 0, "GAIA Fuel Assembly Mechanical Design" (proprietary)
2. ANP-10342NP Rev. 0, "GAIA Fuel Assembly Mechanical Design" (non-proprietary)
3. Affidavit for withholding information in ANP-10342P from public disclosure
4. ANP-10342P topical report prioritization scheme

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is Nathan E. Hottle. I am Manager, Product Licensing, for AREVA Inc. (AREVA) and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA to determine whether certain AREVA information is proprietary. I am familiar with the policies established by AREVA to ensure the proper application of these criteria.

3. I am familiar with the AREVA information contained in the following document: ANP-10342P Revision 0, "GAIA Fuel Assembly Mechanical Design," referred to herein as "Document." Information contained in this Document has been classified by AREVA as proprietary in accordance with the policies established by AREVA Inc. for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by AREVA to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA, would be helpful to competitors to AREVA, and would likely cause substantial harm to the competitive position of AREVA.

The information in this Document is considered proprietary for the reasons set forth in paragraphs 6(b), 6(c) and 6(d) above.

7. In accordance with AREVA's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside AREVA only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

[signature]

SUBSCRIBED before me this 19th day of December, 2016.

[signature]

Sherry L. McFaden
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 10/31/18
Reg. # 7079129

SHERRY L. MCFADEN
Notary Public
Commonwealth of Virginia
7079129
My Commission Expires Oct 31, 2018

<table>
<tr><th colspan="5">TR Prioritization Scheme</th></tr>
<tr><td colspan="5">Title: ANP-10342P "GAIA Fuel Assembly Mechanical Design"</td></tr>
<tr><td>Expect submitting FY</td><td>TAC</td><td>PM</td><td colspan="2">Today's Date: 12/21/2016</td></tr>
<tr><td colspan="2">Technical Review Division(s)</td><td colspan="3">Technical Review Branch(s)</td></tr>
<tr><td>Factors</td><td>Select the Criteria That the TR satisfies</td><td>Points can be Assigned for Each Criteria</td><td colspan="2">Assigned Points</td></tr>
<tr><td rowspan="5">TR Classification
(Select one only)</td><td>Resolve Generic Safety Issue (GSI)</td><td>6</td><td colspan="2" rowspan="5">2</td></tr>
<tr><td>Emergent NRC Technical Issue</td><td>3</td></tr>
<tr><td>New technology improves safety</td><td>2</td></tr>
<tr><td>TR Revision reflecting current requirements or analytical methods.</td><td>2</td></tr>
<tr><td>Standard TR</td><td>1</td></tr>
<tr><td rowspan="3">TR Applicability
(Select one only)</td><td>Potential industry-wide applications</td><td>3</td><td colspan="2" rowspan="3">1</td></tr>
<tr><td>Potentially applicable to entire groups of licensees.</td><td>2</td></tr>
<tr><td>Intended for only partial groups of licensees.</td><td>1</td></tr>
<tr><td rowspan="4">TR Implementation Certainty

(Select one only)</td><td>Industry-wide Implementation expected</td><td>3</td><td colspan="2" rowspan="4">1</td></tr>
<tr><td>Expected implementation by an entire group of licensees (BWROG, PWROG, BWRVIP, etc.) who sponsored the TR.</td><td>2</td></tr>
<tr><td>Docketed intent by U.S. plant(s) but no formal LAR schedule yet</td><td>1</td></tr>
<tr><td>No US plants have indicated strong intent on docket to implement yet.</td><td>0</td></tr>
<tr><td>Tie to a LAR
(Select if applicable)</td><td>A SE is requested by a certain date (less than two years) to support a licensing activity or renewal date (note it in Comments)</td><td>3</td><td colspan="2">3</td></tr>
<tr><td rowspan="4">Review Progress
(Points are cumulative as applicable)</td><td>Accepted for review</td><td>0.3</td><td colspan="2"></td></tr>
<tr><td>RAI issued</td><td>0.5</td><td colspan="2"></td></tr>
<tr><td>RAI responded</td><td>1.2</td><td colspan="2"></td></tr>
<tr><td>SE Drafted</td><td>2.0</td><td colspan="2"></td></tr>
<tr><td colspan="2">Management (LT/ET) discretion adjustment</td><td>-3 to +3</td><td colspan="2"></td></tr>
<tr><td colspan="3">Total Points (Add the total points from each factor and total here):</td><td colspan="2">7</td></tr>
<tr><td colspan="5">Comments: Request Approval by December 2018 for LAR Reference.</td></tr>
</table>

framatome

December 19, 2018
NRC:18:044

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Additional Information Regarding ANP-10342P, "GAIA Fuel Assembly Mechanical Design"

Ref. 1: Letter, Gary Peters (AREVA Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10342P, 'GAIA Fuel Assembly Mechanical Design'," NRC:16:038, December 21, 2016.

In Reference 1, Framatome Inc. (formerly AREVA Inc.) submitted ANP-10342P to the NRC for review and approval. Enclosure 1 of this letter proposes some minor changes to ANP-10342P that, upon approval, will be incorporated into the approved version of ANP-10342P. These changes will necessitate conforming changes to the draft safety evaluation.

Framatome considers some of the material contained in Enclosure 1 to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support withholding of information from public disclosure. A non-proprietary version is included as Enclosure 2.

There are no regulatory commitments within this letter or its enclosures.

If you have any questions related to this information, please contact Mr. Nathan Hottle, Product Licensing Manager, by telephone at (434) 832-3864, or by e-mail at Nathan.Hottle@framatome.com.

Sincerely,

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: J. G. Rowley
Project 728

Enclosures:

1 ANP-10342Q1P Revision 0 (Proprietary)
2 ANP-10342Q1NP Revision 0 (Non-proprietary)
3 Notarized Affidavit

Framatome Inc.
3315 Old Forest Road
Lynchburg, VA 24501
Tel: (434) 832-3000

www.framatome.com

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is Nathan E. Hottle. I am Manager, Product Licensing, for Framatome Inc. (Framatome) and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by Framatome to determine whether certain Framatome information is proprietary. I am familiar with the policies established by Framatome to ensure the proper application of these criteria.

3. I am familiar with the Framatome information contained in the following document: ANP-10342Q1P Revision 0, "GAIA Fuel Assembly Mechanical Design – Additional Information," referred to herein as "Document." Information contained in this Document has been classified by Framatome as proprietary in accordance with the policies established by Framatome Inc. for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by Framatome and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information."

6. The following criteria are customarily applied by Framatome to determine whether information should be classified as proprietary:

(a) The information reveals details of Framatome's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for Framatome.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for Framatome in product optimization or marketability.

(e) The information is vital to a competitive advantage held by Framatome, would be helpful to competitors to Framatome, and would likely cause substantial harm to the competitive position of Framatome.

The information in this Document is considered proprietary for the reasons set forth in paragraphs 6(c) and 6(d) above.

7. In accordance with Framatome's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside Framatome only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. Framatome policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

Nat E. Hall
____

SUBSCRIBED before me this 18 day of December, 2018.

Heidi H Elder
____

Heidi Hamilton Elder
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 12/31/2022
Reg. # 7777873

HEIDI HAMILTON ELDER
COMMONWEALTH
REGISTRATION NO.
7777873
MY COMM. EXPIRES
12/31/2022
OF VIRGINIA
NOTARY PUBLIC

framatome

GAIA Fuel Assembly Mechanical Design

ANP-10342Q1NP
Revision 0

Additional Information

December 2018

Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

1.0 SUMMARY OF ADDITIONAL INFORMATION

The following additional information is being submitted in support of the NRC review of topical report ANP-10342P, "GAIA Fuel Assembly Mechanical Design." The draft safety evaluation identified areas where the scope of ANP-10342P was not consistent with previously-approved fuel assembly design topical reports. While the defined scope of ANP-10342P was intentional, Framatome has reconsidered based on comments in the draft safety evaluation and has decided that the best path forward is to modify the topical report prior to NRC approval to align better with precedent. This change will also clarify the functioning of the design update process described in ANP-10342P. The proposed changes are described below.

Additionally, a few changes are proposed to ANP-10342P to correct minor errors identified in supporting analyses and to clarify certain statements. These changes are also described below.

ANP-10342P markup pages are attached for all the proposed changes. With NRC agreement, Framatome proposes to include these changes in the approved version of ANP-10342P.

1.1 *Changes Associated with Topical Report Scope*

The draft safety evaluation identified that certain evaluations required for consistency with SRP Section 4.2 were not included in ANP-10342P and thus were addressed through limitations and conditions. Framatome's original intent with ANP-10342P was to address only the criteria from SRP Section 4.2 that relate to the mechanical design of the fuel rod and fuel assembly, not the criteria associated with other SRP sections (e.g., SRP Sections 4.3 and 4.4 and Chapter 15). However, after consideration of the draft safety evaluation, Framatome is concerned that the design update process defined in ANP-10342P Section 9.0 is not sufficiently robust if the additional SRP criteria are not stated in this topical report.

The update process allows updates to the GAIA design without prior NRC approval under certain conditions, one being that the GAIA fuel assembly design criteria continue to be met, as demonstrated using NRC-approved methods. Design updates may impact analyses of these additional criteria, so it is desirable to ensure that these analyses are covered under the update process. To do so, Framatome is proposing to add the remaining SRP Section 4.2 fuel criteria to ANP-10342P, noting that the criteria will be evaluated using NRC-approved methods. SRP Sections 4.3 and 4.4 were also screened to identify criteria that need to be included. This change will eliminate the need to tie ANP-10342P to the update process defined in EMF-92-116(P)(A) and will align the scope more consistently with precedent. For convenience and because these additional criteria will be stated but not evaluated in ANP-10342P, they will be added to the end of Section 8.0 instead of interleaving them with the original criteria in Section 8.0.

Topical report markups are included in Appendix A.

1.2 *Minor Corrections and Clarifications*

Fuel rod internal pressure criteria

In Table 3-1 of ANP-10342P under 1.A.vi, the SAFDL states: "Internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation and (2) extensive DNB propagation to occur." Framatome proposes to clarify these criteria to align more directly with SRP Section 4.2. This modification has no impact on how the analyses are performed but is a clearer description of the criteria used. The revised criteria are: "The internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation or (2) reorientation of the hydrides in the radial direction in the cladding." DNB propagation criteria are included in other NRC-approved evaluation methods and are not evaluated as part of ANP-10342P.

Table 3-1 and Section 8.1.6.1 will be revised to state the new criteria. Topical report markups are included in Appendix A.

Fuel rod cladding fatigue

An error was discovered in the calculation of fuel rod cladding fatigue that affects the cumulative usage factor reported in Section 8.1.2.3. The revised cumulative usage factor remains below the approved limit.

Section 8.1.2.3 will be revised to report the corrected cumulative usage factor. Topical report markups are included in Appendix A.

Fuel rod cladding stress

An error was discovered in the calculation of the allowable cladding stress that has a small impact on the fuel rod margins during normal operations. The reported margins for faulted conditions (Table 8-6) are not affected.

Table 8-1 will be revised to report the corrected allowable cladding stress. Topical report markups are included in Appendix A.

Intermediate GAIA mixing grid dimensions

ANP-10342P Section 4.4 states that the intermediate GAIA mixing grids (IGMs) are "made from strips that are thinner and shorter than the GAIA spacer grids." The intent of this statement could be misinterpreted. The geometric differences to which this statement refers are in the axial and lateral directions, not in the thickness of the grid strip, as can be seen in Table 4-3 and Table 4-4. Framatome proposes to change this sentence to read: "To minimize the effect on bundle pressure drop, and to limit the additional material added within the active fuel region, the IGM grids are made from strips that are axially shorter than the GAIA spacer grids."

Section 4.4 will be revised as stated above. Topical report markups are included in Appendix A.

Updated References

ANP-10342P references two topical reports that were not NRC-approved at the time ANP-10342P was submitted. There were no changes to these topical reports as a result of NRC review and approval that impacted the GAIA evaluations presented in ANP-10342P. Section 10.0 will be revised to reference the approved versions of the topical reports. Topical report markups are included in Appendix A.

Miscellaneous Clarifications

The descriptions of a few SRP Section 4.2 acceptance criteria in Table 3-1 were revised to align with the SRP language.

In numerous places in Chapter 8 where the fuel performance code is discussed, a statement was added requiring that the fuel performance code adequately account for pellet thermal conductivity degradation with burnup.

Topical report markups are included in Appendix A.

APPENDIX A – TOPICAL REPORT MARKUPS

The following markups will be incorporated into the NRC-approved version of ANP-10342P.

NUREG-0800 Chapter 4.2 Acceptance Criteria	**GAIA Mechanical Topical Report SAFDL**
1.A.vi Fuel and burnable poison rod internal gas pressures should remain below the nominal system pressure during normal operation or other limits must be justified based on, but not limited to, the following minimum criteria. (1) No cladding liftoff during normal operation (2) No reorientation of the hydrides in th radial direction in the cladding (3) A description of any additional failures resulting from DNB caused by fuel rod overpressure during transients and postulated accidents (see Subsection II, item 1.B.vii)	Section 8.1.6 Internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation ~~and (2) extensive DNB propagation to occur.~~ or (2) reorientation of the hydrides in the radial direction in the cladding. The criteria for DNB propagation are included in other NRC-approved evaluation methods.
1.A.vii Because unseating a fuel bundle may challenge control rod/blade insertion, an evaluation of worst-case hydraulic loads should be performed for normal operation, AOOs, and accidents. These worst-case hydraulic loads for normal operation should not exceed the holddown capability of the fuel assembly (either gravity or holddown springs). Hydraulic loads for this evaluation are reviewed as described in SRP Section 4.4.	Section 8.1.7 During normal operation conditions, the holddown springs shall maintain fuel assembly contact with the lower support plate. Assuming a pump over-speed transient, fuel assembly lift-off can occur but the fuel assembly top and bottom nozzles shall maintain engagement with reactor internal pins and the holddown springs shall maintain positive holddown margin after the event.
1.A.viii Control Rod Reactivity and Insertability	Control rod reactivity and insertability are applicable to the control rod itself, and therefore are not explicitly addressed in this fuel assembly mechanical design topical report.

NUREG-0800 Chapter 4.2 Acceptance Criteria	**GAIA Mechanical Topical Report SAFDL**
1.B.ii If axial gaps in the fuel pellet column result from densification, the cladding has the potential to collapse into a gap (i.e., flattening). Because of the large local strains that accompany this process, collapsed (flattened) cladding is assumed to fail.	Section 8.2.2 Predicted creep collapse life of the fuel rod must exceed the maximum expected in-core life.
1.B.iii ~~Departure from Nucleate Boiling~~ Overheating of Cladding	~~DNB is addressed as part of the plant-specific thermal hydraulic analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~ Section 8.4.1 The criteria for departure from nucleate boiling are included in the NRC-approved critical heat flux correlation topical report for use with the GAIA fuel assembly.
1.B.iv Traditional practice has also assumed that failure will occur if centerline melting takes place. This analysis should be performed for the maximum linear heat generation rate anywhere in the core, including all hot spots and hot channel factors, and should account for the effects of burnup and composition on the melting point. For normal operation and AOOs, centerline melting is not permitted. For postulated accidents, the total number of rods that experience centerline melting should be assumed to fail for radiological dose calculation purposes. The centerline melting criterion was established to assure that axial or radial relocation of molten fuel would neither allow molten fuel to contact the cladding nor produce local hot spots. The assumption that centerline melting results in fuel failure is conservative.	Section 8.2.3 Fuel AOO

NUREG-0800 Chapter 4.2 Acceptance Criteria	GAIA Mechanical Topical Report SAFDL
1.B.v ~~Reactivity Initiated Accident~~ Excessive Fuel Enthalpy	~~Excessive fuel enthalpy is addressed in the plant specific RIA analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~
1.B.vi ~~PCI and/or PCMI~~ Pellet/Cladding Interaction	There are no generally applicable criteria for PCI or pellet to cladding mechanical interac strain SAFD iteria 1.A.i a to SRP a ed to ensur accep l are not explicitly addressed further in this fuel assembly mechanical design topical report. Section 8.4.2 The criteria for excessive fuel enthalpy during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.
1.B.vii ~~Cladding Rupture~~ Bursting	~~Cladding rupture is addressed in the plant-specific LOCA analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~
Section 8.4.4 The criteria for cladding embrittlement during a LOCA are included in the NRC-approved LOCA evaluation methods.	Mechanical fr SAFDL relativ 1.C.v, and the in this fuel as topical report. Section 8.4.3 Cladding swelling and rupture requirements are included in the NRC-approved loss-of-coolant accident (LOCA) evaluation models.
Fuel Coolability	
1.C.i Cladding Embrittlement	~~Cladding embrittlement is addressed in the plant-specific LOCA analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~
1.C.ii Violent Expulsion of Fuel	~~Violent expulsion of fuel is addressed in the plant-specific safety analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~

Section 8.4.5
The criteria for violent expulsion of fuel during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

NUREG-0800 Chapter 4.2 Acceptance Criteria	**GAIA Mechanical Topical Report SAFDL**
1.C.iii Generalized Cladding Melting	Generalized cladding melting is prevented by the more stringent SAFDL associated with SRP acceptance criteria 1.C.i, and therefore not addressed further in this fuel assembly mechanical design topical report.
Section 8.4.6 Fuel rod ballooning requirements are included in the NRC-approved LOCA methods. Fuel Rod Ballooning	~~Fuel rod ballooning is addressed in the plant specific LOCA analyses, and therefore is not explicitly addressed in this fuel assembly mechanical design topical report.~~
1.C.v Structural Deformation NOTE: Acceptance criteria for the evaluation of fuel assembly structural response to externally applied forces are contained in Appendix A Section IV.1 for LOCA and Section IV.2 for safe shutdown earthquake. Two principal criteria apply for the LOCA—(1) fuel rod fragmentation must not occur as a direct result of the blowdown loads and (2) the 10 CFR 50.46 temperature and oxidation limits must not be exceeded. The first criterion is satisfied if the combined loads on the fuel rods and components other than grids remain below the allowable values defined above. The second criterion is satisfied by an ECCS analysis. If combined loads on the grids remain below P(crit), as defined above, then no significant distortion of the fuel assembly would occur and the usual ECCS analysis is sufficient. If combined grid loads exceed P(crit), then grid deformation must be assumed and the ECCS analysis must include the effects	8.3.1 Operational basis earthquake (OBE) stress and load limits are set at the level A limits defined in the ASME Code, unless otherwise specified. Safe shutdown earthquake (SSE) and LOCA stress and load limits are set at the Level D limits defined in the ASME Code, unless otherwise specified.

4.4 *Intermediate GAIA Mixing Grid*

The GAIA fuel assembly incorporates AREVA's current 17x17 PWR Mid Span Mixing Grid (MSMG) design in the form of the IGM. The IGM is based on AREVA's Advanced MK-BW MSMG component, previously approved by the NRC in Reference 10. The IGM grids provide additional flow mixing in the high-heat flux region for improved DNB margin.

axially

Constructed from M5®, the individual strips are slotted and assembled in an egg-crate configuration and welded at each strip intersection. To minimize the effect on bundle pressure drop, and to limit the additional material added within the active fuel region, the IGM ~~spacer~~ grids are made from strips that are ~~thinner and~~ axially shorter than the GAIA spacer grids. The IGM has a smaller envelope than the adjacent GAIA spacer grids, which minimizes mechanical interaction with adjacent fuel assemblies.

Similar to the GAIA spacer grid, the trailing edge of the inner strips is equipped with mixing vanes ensuring efficient mixing. The mixing vane pattern of the IGM is consistent with the GAIA spacer grid.

Stops formed in each of the four cell walls prevent the fuel rods from contacting the mixing vanes, but impose no grip force (or slip load) onto the rods; thus, these are designated "non-contacting" spacer grids. The outer strip design precludes handling damage by incorporating a larger strip thickness (than the inner strips), wrap around corners which are inboard of the square envelope, and large leading and trailing edge lead-in tabs.

The IGM is connected to the guide tubes and instrumentation tube by resistance spot welding four weld tabs at each of the twenty-five locations on the top side of the spacer grid. In addition to maintaining the spacer grid axial positions, the mechanical weld connections help increase the fuel assembly lateral stiffness.

Figure 4-8 through Figure 4-10 and Table 4-4 highlight the IGM grid design features.

The MONOBLOC™ guide tube inner diameter at the top provides an annular clearance that permits rapid insertion of the rod cluster control assembly (RCCA) during a reactor trip. A reduced inner diameter in the dashpot region provides a closer fit with the control rods to decelerate the RCCA. This deceleration limits the RCCA impact loads on the top nozzle. Both inner diameters on the GAIA MONOBLOC™ guide tube are consistent with existing AREVA designs.

The MONOBLOC™ guide tube outer diameter is constant over the entire length, which results in additional material thickness and structural reinforcement in the dashpot region. The outer diameter of the GAIA MONOBLOC™ guide tube was increased to [ ] to improve the overall cage lateral stiffness. This provides additional resistance to twist and bow at high burnups, when spacer grid relaxation significantly reduces the coupling between the fuel rod and structural cage.

Four weep holes in the dashpot region allow coolant outflow during RCCA insertion and coolant inflow to control components during normal operation.

The MONOBLOC™ guide tube is constructed of a new quaternary alloy, Q12™~~, submitted for NRC approval in 2015~~ (Reference 5). Q12™ is an evolutionary development based on AREVA's M5® metallurgy, with low tin and iron added. Tin improves resistance to creep, with its content limited in order not to degrade the corrosion kinetics. Iron, in combination with niobium, is a key element for ensuring good corrosion performance. For structural components, these modifications provide higher irradiation creep strength without compromising the corrosion resistance. Q12™ is processed the same way as M5®, resulting in a fully recrystallized microstructure with fine grains and uniformly distributed precipitates.

The Q12™ instrument tube has a uniform inner and outer diameter. It is centrally located within the 17x17 array, extends the length of the fuel, and is fixed to the cage by resistance welds.

Figure 4-20 and Table 4-6 highlight the guide tube and instrument tube design features.

8.0 DESIGN EVALUATIONS

The SAFDLs established to meet the relevant requirements of the NRC's regulations are provided in the following sections, consistent with the guidelines outlined in NUREG-0800 Chapter 4.2 (Reference 1). As delineated in section 3.0, SAFDLs are provided for fuel system damage, fuel rod failure, and fuel coolability as they relate to the mechanical performance of the fuel. Acceptance criteria associated with the other main areas in NUREG-0800 Chapter 4, including Nuclear Design section 4.3, Thermal and Hydraulic Design section 4.4, and Chapter 15, are not included as part of this topical report. except as noted in Section 8.4.

The ~~mechanical~~ analyses demonstrate that the fuel assembly satisfies the mechanical requirements outlined in NUREG-0800 Chapter 4.2. The calculations are representative of fuel assembly operation in typical three- and four- loop Westinghouse-designed PWR 17x17 fuel plants. The analyses were performed for a peak UO_2 fuel rod burnup of 62 GWd/MTU and peak Gadolinia fuel rod burnup of 55 GWd/MTU. The impacts of coolant flow and temperature, operating power, fuel rod and assembly burnup, dimensional tolerances, irradiation and thermal relaxation, maldistribution, wear, and corrosion were considered.

8.1 *Fuel System Damage*

This subsection relates to the SAFDLs for normal operation, including AOOs as applicable, in addition to shipping and handling conditions. Fuel system damage criteria are included for all known damage mechanisms. Fuel damage criteria assure that fuel system dimensions remain within operational tolerances and that functional capabilities are not reduced below those assumed in the safety analyses. When applicable, the fuel damage criteria consider high burnup effects based on irradiated material properties data.

handling load. Shipping and handling loads are evaluated on an individual guide tube span basis for primary and secondary membrane stress, bending stress, and buckling. Design limits for buckling are based on Euler and/or Timoshenko equations. Q12™ guide tube material properties are used per the applicable material specification, consistent with those in Reference 5 ~~that have been recently submitted to the NRC for approval~~.

- Structural connections are evaluated for a variety of loads for the normal operation and shipping and handling assessments, including those from the assembly weight, grid-to-rod slip loads, holddown spring, and RCCA scram. Calculations are performed at hot operating temperature, a slightly elevated shipping temperature, and room temperature for handling. Structural connection evaluations include weld joint shear strength (e.g. grid-to-guide tube, QD assembly-to-guide tube), lower connection stresses (e.g. membrane, thread shear), and QD component stresses (membrane, bearing).
- Grid evaluations are bounded by a 6g lateral shipping load. The maximum load is calculated at the longest grid span, and is taken as a proportional length fraction of 6 times the total fuel rod weight plus an additional clamping load. The strength of the grids under this mode of loading is conservatively derived from the 95% lower confidence level [ ] Future strength limits can be adjusted to reflect the actual shipping temperature.
- For the M5® fuel rod normal operation assessment, fuel rods are evaluated for steady state cladding stress and buckling. [

]

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA TCS evaluations once applicability is demonstrated.

The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.1.1.3 Stress, Strain, Loading Limits Evaluation

Stress, strain, and load limit calculations were performed for the GAIA structural components, including nozzles, guide tubes, structural connections, grids, and fuel rods. All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

<u>Stress and Load Limits:</u>

Detailed results are tabulated in Table 8-1, representing the limiting margins for the normal operation, shipping, and handling cases.

<u>M5® Fuel Rod Cladding Strain:</u>

Detailed results are tabulated in Table 8-2, representing the bounding TCS LHGR limits for each fuel rod type (UO2, Gadolinia).

<u>Holddown Spring Ultimate Strength:</u>

The holddown spring system is evaluated for normal operating conditions to ensure it [ ] Satisfaction is demonstrated via testing, by verifying that the [ ] Maximum predicted spring deflections occur at cold conditions and are bounded by the tested deflection range. A [ ] does not impact the overall function of the holddown spring system and is accounted for in applicable analyses. Test results verified that the GAIA holddown spring system maintained a [ ]

8.1.2 Strain Fatigue

Cyclic loadings associated with relatively large changes in operating conditions can cause cumulative damage, which may lead to component fatigue failures.

8.1.2.1 Strain Fatigue Design Criteria

For all components other than fuel rod cladding, the CUF shall be less than 1.0. This criterion is in accordance with the ASME Code, Reference 7 (Section III, NG-3222.4). For M5® fuel rod cladding, the CUF shall be less than 0.9. This is in accordance with AREVA criterion previously approved by the NRC in Reference 3.

8.1.2.2 Strain Fatigue Design Method

AREVA uses the general methods prescribed in the ASME Code (Reference 7) to evaluate component fatigue stresses. This is in accordance with AREVA methods previously approved by the NRC in References 3, 8, and 9.

Fatigue performance is evaluated by determining the CUF based on the sum of the individual usage factors for each of the applicable recurring stress events. The O'Donnell Langer curves are used to estimate the corresponding number of allowed cycles of stress for each stress event and associated alternating stress. The design curves include a factor of safety of either 2 on stress or 20 on number of cycles, whichever is more conservative. The CUF is the number of expected cycles divided by the number of allowed cycles.

Specific to fuel rod cladding, the fatigue method is in accordance with section 3.6 of Reference 3. All representative Condition I and II transient events and one representative Condition III event were considered, equivalent to normal operation, AOO's, and postulated accidents respectively. The fuel rod is analyzed using a representative fraction of the number of transients the reactor pressure vessel will experience during its operation. Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fatigue evaluations once applicability is demonstrated.

The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

Evaluation of guide tube fatigue is performed due to their significant load bearing function, in conjunction with their relatively thin walled construction. Guide tube fatigue usage is bounding for other similar components (e.g. ¼-turn QD sleeves). All repetitive loads are considered cyclic and the summation of all hot tensile and cold compressive stresses is determined for each guide tube span. The O'Donnell Langer curve for zirconium alloy material is used for Q12™ to estimate the corresponding number of allowed cycles of stress for each stress event and associated alternating stress.

Evaluation of holddown spring fatigue is performed by combining the usage factors based on normal operation and upset condition reactor coolant system design transients. The alternating stress is calculated by multiplying the strain range by [ ] in the ASME Code (section III, NG-3228), Reference 7.

8.1.2.3 Strain Fatigue Design Evaluation

Fatigue calculations were performed for the GAIA structural components, including fuel rods, guide tubes, and holddown springs. All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

{change to proprietary value}

A limiting fatigue CUF of [ ] was determined for the fuel rod cladding, which is less than the limit of 0.9.

A fatigue CUF of [ ] was determined for the guide tubes, which is less than the limit of 1.0.

A fatigue CUF of [ ] was determined for the holddown springs, which is less than the limit of 1.0.

8.1.4.2 Oxidation, Hydriding, and Crud Methods

The M5® peak cladding oxide thickness calculations are performed in accordance with the NRC-approved COPERNIC methodology in Reference 2. The analysis uses a

[

]

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fuel rod corrosion evaluations once applicability is demonstrated.

The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.1.4.3 Oxidation, Hydriding, and Crud Evaluation

The predicted best estimate peak cladding oxide thickness is [ ] microns, which is less than the limit of 100 microns. This shows that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.1.5 Fuel Rod / Fuel Assembly Bow and Growth

Axial and lateral dimensional changes in the fuel rod and fuel assembly can occur due to irradiation growth, irradiation relaxation, creep, thermal expansion, etc. and can cause component to component or component to core interferences. These may lead to component failures and/or impacts on thermal hydraulic limits, control rod insertion, and/or handling damage.

8.1.5.2 Fuel Rod / Fuel Assembly Bow and Growth Methods

Fuel Rod Bow:

DNBR and LHGR burnup thresholds and penalties are calculated in accordance with the NRC-approved method in Reference 12. The DNBR burnup thresholds are taken as the values at which at least a 50% fuel rod to fuel rod gap closure is predicted, which are the lowest burnups for which a penalty applies. The LHGR burnup thresholds are determined for the lowest burnup where the target LHGR penalty is exceeded.

Fuel Rod and Assembly Growth:

To assess fuel rod and fuel assembly growth, empirical models are used to compute the irradiation growth of the applicable components and the resulting changes are compared with the specified dimensions. This is in accordance with AREVA methods previously approved by the NRC in References 8 and 9.

The upper bound fuel rod growth and lower bound fuel assembly growth is used in conjunction with component manufacturing tolerances to determine the fuel rod shoulder gap margin. The upper bound fuel assembly growth is used in conjunction with component and core plate manufacturing tolerances to determine the fuel assembly gap margin. Limiting burnups and temperatures are considered.

The NRC-approved M5® fuel rod growth model in Reference 9 is used for the fuel rod growth bounds. The Q12™ guide tube growth model in Reference 5~~, recently submitted to the NRC for approval,~~ is used for the fuel assembly growth bounds.

8.1.5.3 Fuel Rod / Fuel Assembly Bow and Growth Evaluation

Fuel Rod Bow:

DNBR and LHGR burnup thresholds are summarized in Table 8-3.

For burnup values below the DNBR and LHGR burnup thresholds, no penalty is applied. For burnup values past the DNBR burnup threshold, the DNBR penalty [ ] No LHGR penalties were applied to the GAIA - IGM grid spans, since the exposure threshold is larger than 62 GWd/MTU. A sample of the LHGR penalties applied to the HMP™ – GAIA and GAIA – GAIA grid spans is provided in Table 8-4.

Fuel Rod and Assembly Growth:

A limiting fuel rod shoulder gap clearance of [ ] inch and fuel assembly core plate clearance of [ ] inch was determined at EOL , showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's.

8.1.6 Fuel Rod Internal Pressure

or (2) reorientation of the hydrides in the radial direction in the cladding.

Excessive pin pressure can cause an increase in the fuel-to-clad gap due to cladding outward creep, which may lead to DNB propagation and component failures.

8.1.6.1 Fuel Rod Internal Pressure Design Criteria

Internal gas pressure of the peak fuel rod in the reactor will be limited to a value below that which would cause (1) the fuel-cladding gap to increase due to outward cladding creep during steady-state operation ~~and (2) extensive DNB propagation to occur.~~ This is in accordance with AREVA criteria previously approved by the NRC in Reference 2.

8.1.6.2 Fuel Rod Internal Press

The criteria for DNB propagation are included in other NRC-approved evaluation methods. DNB propagation is addressed as part of the plant-specific thermal hydraulic analyses.

The fuel rod normal operation intern accordance with the NRC-approved

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA fuel rod pressure evaluations once applicability is demonstrated.

The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

The forces are due to fluid friction loss, buoyancy, momentum change, holddown spring force, and gravity. Forces due to friction losses are obtained through the use of loss coefficients derived from flow testing. Holddown forces are obtained from testing. Fuel assembly dry weight is measured or calculated. Other forces due to momentum and buoyancy are calculated based on the applicable fluid conditions. The evaluation includes the assessment of bounding operating conditions (including coolant temperatures and flowrates, mixed and homogeneous cores, BOL and EOL conditions), component dimensional characteristics (including reactor core plate to core plate and fuel assembly lengths, holddown spring deflections and mechanical set), and material characteristics (including thermal expansion, irradiation growth and relaxation, spring rate). The Q12™ guide tube growth model in Reference 5~~, recently submitted to the NRC for approval,~~ is used to determine the fuel assembly growth bounds. Uncertainties are accounted for using a combination of deterministic and statistical methods.

Other NRC approved methods (e.g. Statistical Holddown, Reference 13), including the associated criteria and methods, may be utilized in the future for GAIA lift-off evaluations once applicability is demonstrated.

8.1.7.3 Fuel Assembly Lift-Off Evaluation

The analysis showed that the GAIA fuel assembly met all lift-off criteria, showing that the GAIA fuel assembly is structurally adequate for all normal operating conditions and AOO's. The fuel assembly will not lift off under cold start-up and normal operating hot conditions, with a minimum margin-to-fuel assembly liftoff of [

]

Future NRC-approved fuel performance codes (e.g. GALILEO), including the associated criteria and methods, may be utilized in the future for GAIA CFM evaluations once applicability is demonstrated.

The fuel performance code must adequately account for pellet thermal conductivity degradation with burnup.

8.2.3.3 Overheating of Fuel Pellets Evaluation

Detailed results are tabulated in Table 8-5, representing the bounding CFM LHGR limits for each fuel rod type (UO2, Gadolinia).

8.3 *Fuel Coolability*

This subsection applies to postulated accidents, specifically their potential impact on control rod insertability and core coolability due to component gross structural deformations.

8.3.1 Structural Deformation

Earthquakes and postulated pipe breaks in the reactor coolant system result in external forces on the fuel assembly. The fuel assembly is designed to withstand these loads from OBE, SSE, and LOCA events without loss of the capability to perform the safety functions that are commensurate with these events.

8.3.1.1 Structural Deformation Design Criteria

OBE, SSE, and LOCA stress and/or load limit criteria are in accordance with section 4 of the PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations topical report (Reference 6). The analyzed events are categorized by different severity levels. OBE stress and load limits are set at the level A limits defined in the ASME Code, unless otherwise specified. SSE and LOCA stress and load limits are set at the Level D limits defined in the ASME Code, unless otherwise specified. Due to their special functions (i.e. forming a path for control rod insertion, ensuring coolable geometry is maintained, protecting the fission product barrier), spacer grids, guide tubes, and fuel rods are subject to more stringent service limits including;

8.3.1.2 Structural Deformation Method

The component OBE, SSE, and LOCA stress and/or load limit calculations are performed in accordance with section 8 of the PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations methodology (Reference 6). The analysis is performed independently in the horizontal and vertical directions using numerical models developed to simulate the mechanical behavior of fuel assemblies. These models capture the motion of the fuel due to the event and the interaction between neighboring fuel assemblies and the baffle as applicable. Results from the horizontal and vertical analyses are used to calculate the maximum design impact loads and stresses which are then compared against the allowable values for each structural component.

8.3.1.3 Structural Deformation Evaluation

All component margins are positive, showing that the GAIA fuel assembly is structurally adequate for all postulated accident conditions and AOO's. Detailed results are tabulated in g margin for the OBE, SSE, and SSE+LOCA

Add new Section 8.4. The current Section 8.4, Design Evaluation Summary, will become Section 8.5.

8.4 *Design Evaluation Summary*

The GAIA fuel assembly was shown to meet all SAFDLs for UO_2 fuel rod burnups up to 62 GWd/MTU and Gadolinia fuel rod burnups up to 55 GWd/MTU. The GAIA design incorporates multiple features that are based on existing AREVA designs with reactor-proven operating experience. This operating experience, coupled with the design verification testing and analyses that demonstrate the acceptability of GAIA's added design features, ensures that the GAIA fuel assembly will operate safely and reliably.

8.0 { NEW SECTION 8.4 }

8.4 *Additional Acceptance Criteria*

This subsection identifies SAFDLs that are not evaluated as part of this topical report. These additional SAFDLs address the remaining fuel design criteria from SRP Section 4.2 and any pertinent criteria from SRP Sections 4.3 and 4.4 that are not covered by the SRP Section 4.2 criteria (Section 8.4.7). With the inclusion of these criteria, this topical report presents a complete set of SAFDLs to be used for evaluation of the GAIA fuel assembly design and in the design update process defined in Section 9.0.

8.4.1 Overheating of Cladding

The criteria for departure from nucleate boiling are included in the NRC-approved critical heat flux (CHF) correlation topical report for use with the GAIA fuel assembly.

Departure from nucleate boiling is addressed in plant-specific thermal hydraulic analyses using NRC-approved methods, including approved mixed core methods. The ORFEO-GAIA and ORFEO-NMGRID correlations are applied to the GAIA fuel assembly as described in Reference 14.

8.4.2 Excessive Fuel Enthalpy

The criteria for excessive fuel enthalpy during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

Reactivity initiated accidents are addressed in plant-specific analyses using NRC-approved methods.

8.4.3 Bursting

Cladding swelling and rupture requirements are included in the NRC-approved loss-of-coolant accident (LOCA) evaluation models.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.4 Cladding Embrittlement

The criteria for cladding embrittlement during a LOCA are included in the NRC-approved LOCA evaluation methods.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.5 Violent Expulsion of Fuel

The criteria for violent expulsion of fuel during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

Reactivity initiated accidents are addressed in plant-specific analyses using NRC-approved methods.

8.4.6 Fuel Rod Ballooning

Fuel rod ballooning requirements are included in the NRC-approved LOCA methods.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.

8.4.7 Reactivity Coefficients

The Doppler coefficient shall be negative at all operating conditions. The power coefficient shall be negative at all operating power levels relative to hot zero power.

Nuclear design criteria are addressed in plant-specific analyses using NRC-approved methods.

Table 8-1 Stress, Strain, Loading Limits Design Margin Summary

[ ]

{change to proprietary values}

10.0 REFERENCES

1. Standard Review Plan, Section 4.2, NUREG-0800 Revision 3, U.S. Nuclear Regulatory Commission, March 2007
2. BAW-10231P-A, Revision 1, COPERNIC Fuel Rod Design Computer Code, January 2004
3. BAW-10227P-A, Revision 1, Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, June 2003
4. BAW-10084P-A, Revision 3, Program to Determine In-Reactor Performance of WFC Fuel Cladding Creep Collapse, July 1995

ANP-10334P-A September 2017

5. ~~ANP-10334P~~, Revision 0, Q12 ™ Structural Material, ~~October 2015~~
6. ~~ANP-10337P~~, Revision 0, PWR Fuel Assembly Structural Response to Externally Applied Dynamic Excitations, ~~August 2015~~ April 2018

ANP-10337P-A

7. American Society of Mechanical Engineers, *Boiler and Pressure Vessel Code*, Section III, Nuclear Power Plant Components, 1992 Edition
8. EMF-92-116P-A, Revision 0, Generic Mechanical Design Criteria for PWR Fuel Designs, February 1999
9. BAW-10240P-A, Revision 0, Incorporation of M5™ Properties in Framatome ANP Approved Methods, May 2004
10. BAW-10239P-A, Revision 0, Advanced Mark-BW Fuel Assembly Mechanical Design Topical Report, July 2004
11. ANF-89-060A and Supplement 1, Generic Mechanical Design Report High Thermal Performance Spacer and Intermediate Flow Mixer, May 1991
12. XN-75-32P-A, Supplements 1, 2, 3, & 4, Computational Procedure for Evaluating Fuel Rod Bowing, October 1983
13. BAW-10243P-A, Statistical Fuel Assembly Holddown Methodology, September 2005

14. ANP-10341P-A Revision 0, The ORFEO-GAIA and ORFEO-NMGRID Critical Heat Flux Correlations, September 2018

framatome

September 6, 2019
NRC:19:023

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Additional Information Regarding ANP-10342P, "GAIA Fuel Assembly Mechanical Design"

Ref. 1: Letter, Gary Peters (AREVA Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10342P, 'GAIA Fuel Assembly Mechanical Design'," NRC:16:038, December 21, 2016.

Ref. 2: Letter, Gary Peters (Framatome Inc.) to Document Control Desk (NRC), "Additional Information Regarding ANP-10342P, 'GAIA Fuel Assembly Mechanical Design'," NRC:18:044, December 19, 2018.

In Reference 1, Framatome Inc. (formerly AREVA Inc.) submitted ANP-10342P to the NRC for review and approval. As a result of discussions between Framatome and NRC regarding the draft safety evaluation report, Framatome is proposing to remove Section 9.0, "Design Update Process," from ANP-10342P. Framatome understands that corresponding sections will be removed from the safety evaluation report.

Enclosure 1 of this letter contains markups to the topical report that will be incorporated into the approved version of ANP-10342P. The markups are shown on the non-proprietary version of the topical report for convenience. Enclosure 1 also contains one markup of a page that was included in a package of proposed changes in Reference 2.

There are no commitments within this letter or its enclosures.

If you have any questions related to this information please contact Mr. Nathan Hottle, Product Licensing Manager, by telephone at (434) 832-3864, or by e-mail at Nathan.Hottle@framatome.com.

Sincerely,

Gary Peters

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: J. G. Rowley
Project 728

Framatome Inc.
3315 Old Forest Road
Lynchburg, VA 24501
Tel: (434) 832-3000

www.framatome.com

Enclosures:

1) ANP-10342 proposed markups

ABSTRACT

The purpose of this topical report is to present the GAIA fuel assembly mechanical design and an evaluation of its mechanical performance on a generic basis. The GAIA design is intended for use in Westinghouse type plants with a 17x17 fuel rod array. The GAIA fuel assembly design is a combination of previously utilized and advanced performance components. This topical report is intended to be referenced in site specific licensing basis documents for plants using the GAIA design.

A discussion of the current regulatory guidance related to fuel assemblies is presented, based on the Nuclear Regulatory Commission's (NRC) Standard Review Plan (SRP), NUREG-0800 Chapter 4.2. A comparison is presented of applicable NUREG-0800 Chapter 4.2 acceptance criteria and the specified acceptable fuel design limits (SAFDLs) established for the GAIA design. The SAFDLs established for the GAIA design have been previously approved for other AREVA fuel assembly designs.

A description of the GAIA fuel assembly design is provided. The components which have been previously utilized and those which are new are identified.

The fuel assembly mechanical tests which have been performed on the GAIA fuel assembly design are summarized.

The relevant operating experience with the GAIA fuel assembly design is summarized.

The Lead Test Assembly (LTA) programs which are ongoing to obtain information regarding the performance of the GAIA fuel assembly design are described.

An evaluation of the performance of the GAIA fuel assembly design for representative operating conditions is presented and compared to the established criteria.

~~A design update process is described which will facilitate future GAIA fuel assembly design changes. The update process defines the conditions under which the design can be modified without NRC review and approval.~~

1.0 INTRODUCTION

AREVA has developed the GAIA fuel assembly design for use in Westinghouse three- and four-loop reactors using a 17x17 fuel rod array. The GAIA design is a combination of previously utilized components and advanced performance components. The primary new features are: GAIA spacer grids, GRIP™ bottom nozzle, and Q12™ guide tube material.

Section 3.0 provides a summary of the regulatory guidance provided in NUREG-0800 Chapter 4.2 related to fuel assemblies, and a comparison to the SAFDLs established for the GAIA fuel assembly design. Section 4.0 describes the GAIA design, highlighting its distinguishing features. Section 5.0 summarizes the mechanical testing performed on the GAIA fuel assembly design. Section 6.0 presents the component operating experience. Section 7.0 presents the associated LTA programs. Section 8.0 provides the results of an evaluation of the GAIA fuel assembly under representative conditions against the SAFDLs defined in Section 3.0 of this report. The SAFDLs established for the GAIA fuel assembly performance are consistent with NUREG-0800 Chapter 4.2 and those previously established in topical reports reviewed and approved by the NRC. ~~Section 9.0 describes an update process to be utilized for future design changes to the GAIA fuel assembly design.~~

Evaluations of the GAIA fuel assembly, which will reference the NRC-approved version of this topical report, will be performed on a plant-specific basis. ~~The design update process described in this report will also be used to justify changes in the GAIA fuel assembly design without specific NRC review and approval.~~

~~9.0 DESIGN UPDATE PROCESS~~

~~This section defines an update process to be used to support updates to the GAIA fuel assembly design which will not require specific NRC review and approval.~~

~~This topical report defines the base GAIA fuel assembly design, provides the GAIA fuel assembly design criteria, and a representative evaluation of compliance to the criteria. The update process includes:~~

- ~~Documenting the fuel assembly design drawings.~~
- ~~Performing analyses with NRC-approved models and methods against the GAIA fuel assembly design specific criteria defined in this topical report (or in separate NRC approved topical reports such as a new fuel rod performance topical report).~~
- ~~Confirming the adequacy of significant new design features using prototype tests or lead test assemblies prior to full reload implementation.~~
- ~~Continuing irradiation surveillance programs, including post irradiation examinations, to confirm fuel assembly performance.~~
- ~~Using the AREVA quality assurance procedures, quality control inspection program, and design control requirements set forth in the NRC-approved quality assurance program.~~
- ~~Notification to the NRC by letter of major updates made to the base GAIA design, either generically or on a plant specific basis.~~

~~Acceptable updates to the GAIA design will meet all of the following conditions:~~

- ~~The GAIA fuel assembly design criteria continue to be met.~~
- ~~No revisions to plant technical specifications are required.~~
- ~~The applicability of NRC-approved methodologies is demonstrated to be valid.~~
- ~~Burnup limits are within those approved by the NRC.~~

~~Design updates shall be developed within the conditions of the NRC-approved criteria and methods.~~

~~Examples of minor design updates that can be made with this update process include but are not limited to:~~

- ~~A design update to the spacer grid to guide tube attachment.~~
- ~~A design update to the spacer grid strip thickness and/or material.~~
- ~~A design update to the cladding thickness.~~
- ~~The first use of an assembly design feature previously irradiated in conjunction with one lattice (i.e. 17x17) in a different lattice (i.e. 14x14).~~
- ~~A design update to the enrichment.~~
- ~~A design update to the Gadolinia bearing rod locations.~~
- ~~A design update to the plenum spring material and/or addition of a lower plenum spring.~~

~~Examples of major design updates are:~~

- ~~New cladding material.~~
- ~~A spacer grid with a new functional mixing behavior or new rod support mechanism.~~
- ~~A design update that would alter the fuel behavior relative to NRC-approved models outside of any update process approved for use with those models or topical reports.~~

~~A separate topical report would generally be required to justify revised methodologies necessary to analyze major design updates. Once the updated methodology is approved and demonstrated to be applicable to the GAIA fuel assembly design, its application to the GAIA design would be made in accordance with this update process.~~

~~The GAIA fuel assembly design specific criteria defined in this topical report may be revised if revised criteria have been approved in a separate topical report. For example, a new fuel rod performance code/methodology may be approved with revised fuel rod criteria. If a new fuel rod performance code/methodology were used for the GAIA fuel assembly design then the corresponding criteria would replace those defined in this report.~~

~~In summary, the update process described in this section will be used to justify updates to the GAIA fuel assembly design without requiring NRC review and approval when this topical report is referenced.~~

~~Both minor and major design updates will be made, justified, and documented in AREVA internal documents. An information letter will be sent to the NRC for major design updates. This information letter will describe the update to the design and summarize the design analyses performed to support comparison to the design criteria. No notification will be provided for minor design updates.~~

8.0 { NEW SECTION 8.4 }

8.4 *Additional Acceptance Criteria*

This subsection identifies SAFDLs that are not evaluated as part of this topical report. These additional SAFDLs address the remaining fuel design criteria from SRP Section 4.2 and any pertinent criteria from SRP Sections 4.3 and 4.4 that are not covered by the SRP Section 4.2 criteria (Section 8.4.7). With the inclusion of these criteria, this topical report presents a complete set of SAFDLs to be used for evaluation of the GAIA fuel assembly design ~~and in the design update process defined in Section 9.0~~.

8.4.1 Overheating of Cladding

The criteria for departure from nucleate boiling are included in the NRC-approved critical heat flux (CHF) correlation topical report for use with the GAIA fuel assembly.

Departure from nucleate boiling is addressed in plant-specific thermal hydraulic analyses using NRC-approved methods, including approved mixed core methods. The ORFEO-GAIA and ORFEO-NMGRID correlations are applied to the GAIA fuel assembly as described in Reference 14.

8.4.2 Excessive Fuel Enthalpy

The criteria for excessive fuel enthalpy during a reactivity initiated accident are included in the NRC-approved control rod ejection methods.

Reactivity initiated accidents are addressed in plant-specific analyses using NRC-approved methods.

8.4.3 Bursting

Cladding swelling and rupture requirements are included in the NRC-approved loss-of-coolant accident (LOCA) evaluation models.

LOCAs are addressed in plant-specific analyses using NRC-approved methods.