AREVA

ANP-10338Q2
Revision 0

Response to Request for Additional Information – ANP-10338P

Topical Report

August 2017

AREVA Inc.

Nature of Changes

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

Contents

List of Tables

Nomenclature

Acronym	Definition
FRM	Fuel Rod Model
MDNBR	Minimum Departure from Nucleate Boiling Ratio
RAI	Request for Additional Information

Introduction

The United States Nuclear Regulatory Commission (NRC) provided a request for additional information (RAI) regarding the topical report ANP-10338 (Reference 1) in Reference 2. One question was received from the NRC.

1.0 RAI 2

Question:

The methodology for the ARCADIA Rod Ejection Accident (AREA™) analysis code (ANP-10338P, Revision 0) is predicated on the NRC approved methodology of the ARCADIA® code system (ANP-10297P and ANP-10297P-A, Revision 0, Supplement 1). However, in lieu of the fuel rod model (FRM) of the approved ARCADIA® code system, AREA™ applies the NRC unapproved fuel performance code GALILEO (ANP-10323P) to provide the thermal-mechanical properties of the fuel pins for analyses performed with AREA™. In line with the Update Process set forth in Section 6.1 of ANP-10338P, Revision 0, for including codes without current NRC approval, this RAI requests the following information.

A. Justify the motivation for using GALILEO derived thermal-mechanical properties of fuel pins rather than those of the NRC approved FRM in ARCADIA®.

B. List the capabilities that are introduced by the GALILEO models to ARCADIA® that either do not exist or introduce better estimates with less uncertainty of the figures of merit for meeting regulatory reactivity-insertion accident (RIA) acceptance criteria.

C. The FRM in the ARCADIA® code solves the heat transfer equation given by Equation 5-1 in ANP-10297P, Revision 0. Is the FRM thermal solver identical to the one in GALILEO?

D. The thermal equation solver given by Equation 5-1, in order to compute the time-dependent spatial distribution of the local temperature, requires values for the spatially dependent local heat generation source term, local thermal conductivity, local specific heat, and local density. The description for the computation of the thermal models for these physical properties is given, in the case of GALILEO, in Chapter 5 of GALILEO Fuel Rod Performance Code Theory Manual FS1-0004682, Revision 2.0. Comparable detailed descriptions do not exist in the ARCADIA® topical report.

Thus, in the context of the supplementary summary of the interfaces with GALILEO in the AREA™ methodology, submitted by AREVA to facilitate a teleconference with NRC on May 31, 2017 (shown below), the following information is requested.

i. Indicate for the six usages in the context of the GALILEO models given in Chapter 5 of the GALILEO Theory Manual the differences, if any, with the models in FRM of ARCADIA® for the lookup tables for the requisite spatially dependent physical constants or the information for the post processing of the ARTEMIS™ results.

ii. Is the radially dependent source computed with the same codes and fitting procedures in FRM and GALILEO?

iii. Furthermore, indicate which differences delineated above are the main contributors to the ARTEMIS™– GALILEO differences shown in Figures 5-2 through 5-7 in the AREA™ topical report under review.

<u>Interfaces with GALILEO</u>

The different uses of the fuel rod code in AREA™ to determine fuel pin performance relative to the RIA criteria are highlighted below by showing the use of GALILEO™ in the sample problems. There are six different types of usage of the data as listed below. Note that any of this information can be derived from any NRC approved fuel rod code and that information from GALILEO™ for AREA™ would only be used after its approval by the NRC.

1. The fuel rod thermal properties are equations included in the ARTEMIS™ Fuel Rod Module and are listed below. The ARTEMIS™ default equations are equivalent to the thermal property equations in GALILEO™.
   a. For uranium oxide (UO_2), UO_2-Gd_2O_3 [gadolinium oxide], zircaloy-4 (Zr4), and M5 clad
      i. Thermal conductivity
      ii. Specific heat

   b. Fuel pellet radial power profile fit function

2. Data generated by GALILEO™ computer runs that are used as input (lookup tables) to ARTEMIS™.

   a. Gap Conductance

   b. Porosity (used to calculate fuel thermal conductivity)

3. Data generated by GALILEO™ are compared to ARTEMIS™ results to verify the adequacy of the gap conductance lookup table model in ARTEMIS™.

   a. Fuel centerline, average, and surface temperatures

   b. Clad internal and average temperatures

4. The GALILEO™ equations that are used to post process the ARTEMIS™ results.

   a. Fuel melt temperature equation and its uncertainty for UO_2 and UO_2-Gd_2O_3

5. Data generated by GALILEO™ that are used to post process the ARTEMIS™ results for comparison to limiting conditions for RIA criteria.

   a. Maximum rim burnup versus average pellet burnup for rim melt temperature

   b. Clad corrosion versus burnup to convert to enthalpy rise failure limits

   c. Max internal pressure and back fill pressure versus burnup for pressure related requirements

   d. Fission gas release versus burnup

6. The following data from GALILEO™ models are used for AREA™ sensitivity studies to establish the need for biasing.

   a. Uncertainties for thermal conductivity and specific heat

   b. Oxide results

   c. Fuel expansion

Response 2.A:

The thermal properties in the approved Fuel Rod Model in ARCADIA® are not changed for AREA™. The FRM model in ARCADIA® obtained its thermal properties from a development version of GALILEO™. Hence, ARCADIA® and GALILEO™ have the same thermal properties which are listed in Table 1-1.

Therefore, the motivation for AREA™ is to remain consistent with both ARCADIA® and GALILEO™ and no further justification will be needed for this when GALILEO™ is approved. If another fuel performance code is used, justification would be developed for (1) using its thermal properties in ARCADIA® or (2) a justification would be developed for not changing the thermal properties in ARCADIA® (that is using the GALILEO™ properties that are in ARCADIA® currently). It is anticipated that the use of the second option will be feasible.

Response 2.B:

There are no changes to the ARCADIA® model due to the use of GALILEO™ in AREA™. In order to show compliance with the RIA criteria for control rod ejection accidents, AREA™ requires a model to calculate the thermal conditions of specific fuel pins and ARCADIA® has only a nodal model (4 radial nodes per assembly). For example, the thermal conductivity for a fuel pin containing various amounts of Gadolinia is different than UO_2 which affects the calculation of the fuel temperature. The capabilities of GALILEO™ that are utilized in AREA™ to calculate the pin specific parameters that are not available from ARCADIA® are:

- Calculate clad corrosion to determine enthalpy rise limits
- Pin internal pressures for fuel cladding failure criteria due to high temperature
- Pin internal pressures used to address potential coolability concerns
- Fuel melt temperature limit
- Rim burnup as a function of pellet burnup used to preclude rim melting

- Estimated uncertainties of the fuel properties for sensitivity analysis
- Pellet specific gap conductance and porosity tables are used in the detailed model to calculate specific pin properties (i.e. Gadolinia pins)

Response 2.C:

The FRM thermal solver is not identical to the solver in GALILEO™. The FRM thermal solver is described in Section 5 of Reference 3. The key differences between the GALILEO™ and ARCADIA® FRM are shown in Table 1-2.

Response 2.D:

Table 1-3 describes the differences expected from using the ARCADIA® FRM model for each of the listed applications for AREA™.

As noted in the response to RAI.2A, the FRM in ARTEMIS™ uses the same radial power profiles as GALILEO™.

The FRM thermal calculations in ARTEMIS™ using static gap conductance tables compared to those in GALILEO™ which use dynamic gap conductance is the primary cause of the differences of the results in these figures.

Table 1-1
ARCADIA® and GALILEO™ Thermal Properties

Thermal Parameter	ARCADIA® (Reference 3)	GALILEO™ (Reference 4)
UO_2 thermal conductivity	Same source as GALILEO™	Section 5.6.2.1 in Reference **4**
UO_2 –Gd_2O_3 thermal conductivity	Same source as GALILEO™	Section 5.6.2.4 in Reference **4**
Zr4 thermal conductivity	Same source as GALILEO™	Section 9.5.2 in Reference **4**
M5 thermal conductivity	Same source as GALILEO™	Section 9.5.3 in Reference **4**
Fuel specific heat	Same source as GALILEO™	Section 9.6.4 in Reference **4**
Zr4 specific heat	Same source as GALILEO™	Section 9.6.2 in Reference **4**
M5 specific heat	Same source as GALILEO™	Section 9.6.3 in Reference **4**
Fuel pellet radial power profile	Same source as GALILEO™	Section 5.2 in Reference **4**

Table 1-2
Important Differences between ARCADIA® FRM and GALILEO™ Models

Phenomena	ARCADIA®	GALILEO™
Gap Conductance	A contact resistance formulation is used for gap conductance that does not require a gap thickness for its solution and uses a fitting table for the gap conductance.	Detailed thermal expansion, mechanical deformation, and fission gas release models are used to calculate the pellet-clad gap, contact pressure, and gap gas content to calculate the gap conductance.
Coolant Properties	The thermal hydraulic module is a time dependent, 1D energy and momentum balance with cross flow and calculates the thermal properties of the coolant for the node and pin coolant channels. See section 4.0 of Reference 3.	A simple static energy balance using a closed channel thermal model is used for the coolant thermal properties of the pin. (This coolant model is not capable of calculating prompt critical transients.)
Corrosion Model	No corrosion is used in the thermal solution of the FRM for the sample problems. A sensitivity study on clad conductivity (identified in Table 4-3 of Reference 1 is performed to assess no corrosion as a part of the Section 7 sensitivity evaluation in Reference 1.	A detailed corrosion and crud model is needed to determine the corrosion based RIA criteria.

Table 1-3
Expected Result Differences Between ARCADIA® FRM and GALILEO™

Usage	Expected differences
1. Fuel Thermal Properties	Since the same source for this information is used in the ARCADIA® FRM and GALILEO™, no significant differences are expected.
2a. Gap Conductance Tables	GALILEO™ is used to calculate these tables. The expected temperature errors are estimated and assessed in Section 5.2.2 of Reference 1.
2b. Porosity	The porosity is a very slow changing correction with burnup. The fitting table versus burnup obtains the primary radial variation of the porosity with burnup. No significant differences are expected.
3. Benchmarks	This use of GALILEO™ assesses the differences primarily of 2a but would also include all solution differences. The outer clad temperature is fixed so that the coolant model is not a source of error in these benchmarks. (Section 5.2.2 of Reference 4) Also, both GALILEO™ and ARCADIA® FRM use no corrosion for these benchmarks.
4. Melt temperature	Melt temperatures are defined in GALILEO™ as a function of burnup. Maximum and rim temperature predictions by the FRM are assessed in Section 5.2.2 of Reference 1.
5a. Rim Burnup	Rim burnups are conservatively estimated with GALILEO™ runs to determine the melt temperature of the rim. The temperature prediction of the FRM is compared to this limit.
5b. Clad corrosion	GALILEO™ is used to estimate the amount of corrosion that occurs with burnup. Sensitivity calculations to identify the key parameters in Chapter 7 of Reference 1 determined that ignoring clad corrosion had an insignificant impact on the dependent variables (MDNBR, maximum fuel temperature, total enthalpy, rim temperature, enthalpy rise, and integrated power to the coolant).
5c. and d. Internal Pressure and fission gas release	GALILEO™ is used to conservatively estimate these variables using a conservative pin power history as described in Section 6.2.2 of Reference 1. These are long term steady state effects and there is no direct relationship to the FRM.

6. Sensitivity Studies	These studies are performed using the ARCADIA® nodal and detailed models to assess the importance of ignoring or biasing different parameters. Estimated uncertainties of the thermal properties from GALILEO™ are used to validate the biasing model of AREA™. GALILEO™ does not have a gap conductance model uncertainty; rather it is included in the overall prediction of temperature uncertainty. GALILEO™ estimates the effect of manufacturing tolerances on the gap conductance through direct simulations. The gap conductance model in the ARCADIA® FRM is also tested with sensitivity studies using a multiplier of 2.0 and 0.5 on the calculated value and also investigates manufacturing tolerances.

2.0 REFERENCES

1. ANP-10338P Revision 0, "AREA™ – ARCADIA® Rod Ejection Accident," October 2015.
2. Letter, Jonathan G. Rowley (NRC) to Gary Peters (AREVA Inc.), "Request for Additional Information Re: AREVA Inc. Topical Report ANP-10338P, 'AREA – ARCADIA Rod Ejection Accident'," (CAC No. MF7009), July 31, 2017.
3. ANP-10297P-A, "The ARCADIA® Reactor Analysis System for PWRs Methodology Description and Benchmarking Results," February 2013.
4. FS1-0004682-2.0, "GALILEO Fuel Rod Performance Code Theory Manual," May 2013. Provided to the NRC in Reference 5.
5. Letter, Pedro Salas (AREVA Inc.) to Document Control Desk (NRC), "Documents to Support the NRC Review of ANP-10337P, 'Fuel Rod Thermal Mechanical Methodology for Boiling Water Reactors and Pressurized Water Reactors'," NRC:13:073, September 17, 2013.