framatome

GALILEO Implementation in LOCA Methods

ANP-10349NP-A
Revision 0

Topical Report

November 2021

FRAMATOME TRADEMARKS

GALILEO, M5 and M5Framatome are trademarks or registered trademarks of Framatome or its affiliates, in the US or other countries.

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

November 15, 2021

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

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME TOPICAL REPORT ANP-10349P, REVISION 0, "GALILEO IMPLEMENTATION IN LOCA METHODS" (EPID L-2020-TOP-0059)

Dear Mr. Peters:

By letter dated October 7, 2020, Framatome, Inc. (Framatome) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval of Topical Report (TR) ANP-10349P, Revision 0, "Galileo Implementation in LOCA Methods" (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20290A663) for review and approval. By letter dated November 30, 2020 (ADAMS Accession No. ML20336A164), the NRC staff accepted the TR for review.

By letter dated August 31, 2021 (ADAMS Package Accession No. ML21209A025), an NRC draft safety evaluation (SE) regarding our approval of ANP-10349P, Revision 0, was provided for your review and comment. By letter dated September 28, 2021 (ADAMS Package Accession No. ML21277A207), you provided comments on the draft SE. The NRC staff's disposition of the Framatome comments on the draft SE are discussed in the attachment of the final SE enclosed with this letter.

The NRC staff has found that TR ANP-10349P, 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 applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant specific review in accordance with applicable review standards.

NOTICE: The enclosure to this letter contains Proprietary Information. When this letter is separated from the enclosure, this letter is decontrolled.

In accordance with the guidance provided on the NRC website, we request that Framatome publish approved proprietary and non-proprietary versions of TR ANP-10349P, Revision 0, within three months of receipt of this letter. The approved versions shall incorporate this letter and the enclosed final SE after the title page. For non-proprietary versions, Framatome shall strike the proprietary information markings in this letter and make the appropriate redactions and adjustments to document security classifications to the enclosed SE. Also, they must contain historical review information, including NRC request for additional information (RAI) questions and your responses. The approved versions shall include a "-A" (designating approved) following the TR identification symbol.

As an alternative to including the RAI questions 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 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 RAI questions:

1. The RAI questions and RAI responses can be included as an Appendix to the accepted version.

2. The RAI questions 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 RAI questions 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,

/RA/

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

Docket No. 99902041
Project No. 728

Enclosure: Final SE (Proprietary)

SUBJECT: FINAL SAFETY EVALUATION FOR FRAMATOME TOPICAL REPORT ANP-10349P, REVISION 0, "GALILEO IMPLEMENTATION IN LOCA METHODS" (EPID L-2020-TOP-0059)
DATED: NOVEMBER 15, 2021

DISTRIBUTION:
PUBLIC (Letter)
NON-PUBLIC (Final SE)
RidsResOd Resource
RidsNrrOd Resource
RidsNrrDss Resource
RidsNrrLADHarrison Resource
RidsNrrDorl Resource
RidsNrrDorlLlpb Resource
RidsOgcMailCenter Resource
RidsACRS_MailCTR Resource
RLukes, NRR
MPanicker, NRR
NOtto, NRR
DMorey, NRR

ADAMS Accession Nos.:
ML21286A771 (Package)
ML21286A598 (Letter)
ML21286A729 (Final SE)

***concurrence via e-mail**

OFFICE	NRR/DORL/LLPB/PM*	NRR/DORL/LLPB/LA*	OGC – NLO	NRR/DSS/SNPB/BC*
NAME	NOtto	DHarrison	DRoth	RLukes
DATE	10/13/2021	10/21/2021	11/12/2021	11/15/2021
OFFICE	NRR/DORL/LLPB/BC*			
NAME	DMorey			
DATE	11/15/2021			

OFFICIAL RECORD COPY

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

FOR FRAMATOME, INC. TOPICAL REPORT ANP-10349P, REVISION 0,

"GALILEO IMPLEMENTATION IN LOCA METHODS"

PROJECT NO. 710; DOCKET NO. 99902041

(EPID L-2020-TOP-0059)

1.0 INTRODUCTION

In ANP-10349P TR (Ref. 1), Framatome seeks NRC staff approval to implement the approved GALILEO fuel performance code (FPC) (Ref. 2) in S-RELAP5 in the small break Loss of Coolant Accident (SBLOCA) (Ref. 6) and Realistic Large Break LOCA (RLBLOCA) (Ref. 5) methodologies for Westinghouse and Combustion Engineering (CE) design Pressurized Water Reactors (PWRs) with recirculation (U-tube) steam generators, fuel assembly lengths of 14 feet or less, and emergency core cooling system (ECCS) injection to the cold legs. Currently, the Loss of Coolant Accident (LOCA) evaluation models (EMs) for Westinghouse and CE designed PWRs use S-RELAP5 as system thermal hydraulics code, that uses input from FPC such as COPERNIC for realistic large-break LOCA (RLBLOCA) or RODEX2 for small-break LOCA (SBLOCA) (Refs. 3 and 4).

In order to confirm the analyses and references supporting any future licensing action, the NRC staff performed a virtual audit (Ref. 7) of the listed documents related to implementation of GALILEO code and methodology in Framatome's LOCA analyses on February 10-12, 2021. The audit generated a report (Ref. 8) and a list of requests for additional information (RAIs) (Ref. 9). Framatome, by letter dated April 23, 2021 (Ref. 10), responded to the RAIs.

The NRC staff has reviewed the TR, the response to the RAIs, and all the related documents. A safety evaluation (SE) for the TR follows.

2.0 REGULATORY EVALUATION

The NRC staff performed its review using the Standard Review Plan (SRP) for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-0800). Applicable chapters included Chapter 6.3, "Emergency Core Cooling System," and Chapter 15.6.5, "Loss of Coolant Accidents."

Chapter 6.3 of SRP provides guidance for performing reviews related to safety analysis regarding the ECCS for Boiling Water Reactors (BWRs) and PWRs. The specific areas include the requirements for 10 CFR 50.46, "Acceptance Criteria for ECCS for Light-water Nuclear Power Reactors," ECCS acceptance criteria and performing all the functions required by the design bases.

Chapter 15.6.5 of the SRP provides guidance for performing reviews of LOCA analyses for the spectrum of postulated pipe breaks within the reactor coolant pressure boundary.

These SRP chapters provide guidance to the NRC staff in performing the safety review of ANP-10349P, Revision 0. They describe methods or approaches that the NRC staff has found acceptable for meeting NRC requirements.

Additional requirements, which govern assumptions that must be employed in the ECCS evaluation, are contained in 10 CFR Part 50 Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion (GDC) 35, "Emergency Core Cooling," which states:

> A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that: (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.
>
> Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

3.0 TECHNICAL EVALUATION

This technical evaluation describes the NRC staff assessment of technical adequacy and regulatory compliance of the Framatome's process in replacing the COPERIC and RODEX2 FPCs with the NRC staff approved GALILEO (Ref. 2) in both RLBLOCA and SBLOCA evaluation models.

The NRC staff reviewed the analysis where the FPC COPERNIC is supplemented with recently approved FPC GALILEO (Ref. 2) in the thermal hydraulics code, S-RELAP5. The NRC staff review included verification of original Phenomena Identification and Ranking Table (PIRT) phenomena inputs into the S-RELAP5 code coupled with GALILEO and compare the results from the S-RELAP5/GALILEO combination with the results from original S-RELAP5/COPERNIC combination for RLBLOCA calculations and also compare the results from the S-RELAP5/GALILEO combination for the SBLOCA calculations and compare the results from the S-RELAP5/RODEX2 combination.

The NRC staff review also included the simulation of LOCA using the Loss of Fluid Test (LOFT) facility which is a scaled down version of a 4-loop Westinghouse PWR. The review included the verification of the reproducibility of LOFT for PWR LOCA, verification of inputs to LOFT test and review of the results from the LOFT test to examine whether the results conform with the previous LOFT experiments with RLBLOCA and SBLOCA. The NRC staff review also focused on Framatome's execution of sample problem for both RLBLOCA and SBLOCA. Framatome executed sample problem using a Westinghouse 3-loop design with dry atmospheric containment. The loop contains three reactor coolant pumps (RCPs), three U-tube steam generators, and a pressurizer. The sample problem analysis was reviewed by the NRC staff to determine whether the results conform with the applicable SRP guidelines and regulations mentioned in Section 2.0, "Regulatory Evaluation."

The technical evaluation consists of brief description of computer codes used in this TR (Section 3.1, "Computer Codes Relevant to Topical Report ANP-10349P"), review of how GALILEO code is implemented in S-RELAP5 and in RLBLOCA analysis (Sections 3.2, "GALILEO Implementation in S-RELAP5," and 3.3, "GALILEO Implementation in RLBLOCA EM"), LOFT experiments and analysis of results (Section 3.4, "Assessment of S-RELAP5/GALILEO Results from Integral LOFT Large Break Tests"), and sample problem and verification of results (Section 3.5, "RLBLOCA Sample PWR Problem with GALILEO"). Section 3.6, "GALILEO Implementation in the SBLOCA EM," of the SE describes how the Framatome used GALILEO in the SBLOCA analysis and review details of the results from LOFT tests and sample problems.

3.1 COMPUTER CODES RELEVANT TO TOPICAL REPORT ANP-10349P

S-RELAP5

NRC-approved S-RELAP5 evolved from Framatome's ANF-RELAP code which is a modified RELAP5/MOD2 used by Framatome for performing PWR plant licensing analyses including RLBLOCA and SBLOCA analyses, steam line break analysis, and PWR non-LOCA SRP Chapter 15 event analyses. The code structure of S-RELAP5 is modified to be essentially the same as that for RELAP5/MOD3, with the similar code portability features.

GALILEO

NRC-approved GALILEO is a best-estimate FPC that predicts the thermal-mechanical behavior of PWR fuel rods. ANP-10323 (GALILEO TR) (Ref. 2) presents a methodology for the realistic evaluation of the thermal-mechanical performance of fuel rods for PWRs. The GALILEO TR has two components. The first component is the best estimate fuel rod performance code GALILEO. The GALILEO code models the thermal-mechanical behavior of the fuel rods during normal operation and transient scenarios. The second component of the realistic thermal-mechanical fuel rod performance methodology is the application of the code for evaluating the behavior of rods under normal operation and transient conditions by providing initial conditions for the analyses.

3.2 GALILEO IMPLEMENTATION IN S-RELAP5

For each time step calculations in S-RELAP5, the fuel rod models are coupled with the FPC (GALILEO code) to recalculate fuel rod thermal properties. The coupling scheme used for GALILEO is [ ] Framatome, in response to an NRC-staff RAI (Ref. 10) describe [ ] The data exchange between GALILEO and S-RELAP5 [ ] The GALILEO FPC code coupled with S-RELAP5 uses [ ]. In response to RAI 1.b, Framatome provided the results obtained from [ ] The NRC staff reviewed the details of the [ ] and the NRC staff determined that the fuel rod properties that are passed from

GALILEO to S-RELAP5 solved the Peak Cladding Temperature (PCT) and Maximum Local Oxidation (MLO) which are [ ] coupled calculations.

3.3 GALILEO IMPLEMENTATION IN THE RLBLOCA EM

This section describes how the NRC staff reviewed the process where GALILEO code is implemented in RLBLOCA analysis replacing the use of COPERNIC FPC with GALILEO. The PIRT process in Table 5-1, "Phenomena Identification and Ranking Table for PWR LBLOCA," of Reference 5, provides the application domain for RLBLOCA EM for prioritizing the importance of the LOCA associated phenomena. The NRC staff reviewed the selected PIRT parameters which are specific to the transients and the power plant type analyzed. The new FPC, GALILEO [ ] The supplemental RLBLOCA EM (ANP-10349P) with Supplemented GALILEO FPC [ ] This means that [ ] selected by Framatome as listed in Table 3-1, "Phenomena Identification and Ranking Table for EM Changes to PWR RLBLOCA," of Reference 1 [ ] The NRC staff checked the priority and validity of the PIRT parameters with the original PIRT parameters in the approved RLBLOCA methodology TR, EMF-2103-P-A Revision 3 (Ref. 5). The NRC staff verified the PIRT parameters which are the processes during a LOCA such as blowdown, refill and reflood and [ ] For all the fuel performance parameters that had been used in the GALILEO/RLBLOCA, the NRC staff confirmed that [ ].

The NRC staff verified these PIRT parameters and determined that they are in line with the PIRT parameters associated with the original PIRT parameters used in the approved RLBLOCA methodology TR, EMF-2103-P-A Revision 3.

3.4 ASSESSMENT OF S-RELAP5/GALILEO RESULTS FROM INTEGRAL LOFT LARGE BREAK TESTS

The LOFT tests were used to assess the base for the supplemental RLBLOCA EM (Ref. 1) and benchmark the results using the coupled S-RELAP5/GALILEO. The LOFT facility was designed by the NRC to simulate the nuclear and thermal-hydraulic phenomena that occurs in PWR during LBLOCA. It is a scaled down PWR facility designed to simulate the system response of a 4-loop Westinghouse PWR during a hypothetical LBLOCA (Figures 3-4, "Schematic View of the LOFT Test Facility," and 3-5, "LOFT Large Break Model Nodalization," of Ref. 1). The facility description, large break tests, and input development have been included in Section 3.6.1, "LOFT Large Break Tests L2-3, L2-5, LP-02-6 and LP-LB-1," of Reference 1. The NRC staff reviewed four different LOFT tests: L2-3, L2-5, LP-02-6 and LP-LB-1, inputs to these tests and the results obtained from these tests. These tests were repeated for this TR to compare the results of GALILEO/S-RELAP5 to COPERNIC/S-RELAP5 combination. Table 1 below shows conditions under which these tests were conducted.

Table 1: LOFT Tests and their Conditions

Test	Test Conditions	Test Results
L2-3	4-Loop PWR, Unpressurized nuclear fuel rods, Reactor power heat source, Double ended cold-leg guillotine break, test initiated at 75 percent thermal power, 11.9 kilowatt-per foot (kW/ft) linear heat generation rate (LHGR)	Table 3-5, "Comparison of S-RELAP5 and LOFT L2-3 Steady-State Conditions," of Reference 1 S-RELAP5/GALILEO results agree with test results.
L2-5	Similar conditions as L2-3; 12.2 kW/ft LHGR	Table 3-8, "Comparison of S-RELAP5 and LOFT L2-5 Steady-State Conditions," of Reference 1 S-RELAP5/GALILEO results agree with test results.
L2-6	Pressurized nuclear fuel rods, minimum ECCS injection rates, maximum linear heat generation rate (MLHGR) is 14.9 kW/ft (Typical for 15x15 fuel array).	Table 3-11, "Comparison of S-RELAP5 and LOFT LP-02-6 Steady-State Conditions," S-RELAP5/GALILEO results agree with test results.
LP-LB01	Initiated from conditions representative of a PWR operating in its licensing limits, 50 megawatt thermal (MWt) with MLHGR of 15.8, Loss-of offsite power (LOOP), rapid RCP coastdown, minimum safeguards ECCS injection.	Table 3-14, "Comparison of S-RELAP5 and LOFT LP-LB-1 Steady-State Conditions," S-RELAP5/GALILEO results agree with test results.

As seen from Table 1, the LOFT tests were simulated with all possible combination of reactor conditions. The NRC staff reviewed the initial conditions used in each of the tests, event sequences for each of the tests, and the results as listed in Tables 3-5, 3-8, 3-11 and 3-14 of Reference 1. The NRC staff's review confirmed that Framatome used similar procedures for these tests as in the approved RLBLOCA EM and methodology TR (EMF-2103-P-A, Revision 3). The LP-LB01 test complies with GDC-35 since it requires that a system be designed to provide abundant core cooling with suitable redundancy such that the capability is maintained during LOOP.

For all of the above tests, the results from the S-RELAP5/GALILEO coupled method [ ]. Therefore, the NRC staff determined that the supplement of COPERNIC FPC with GALILEO FPC in S-RELAP5 [ ] thereby confirming that the supplemental evaluation model is acceptable for LBLOCA analysis.

The NRC staff reviewed the Framatome's LOFT benchmarking of S-RELAP5 thermal hydraulics code with the NRC approved GALILEO FPC and confirmed that the parameters obtained from this benchmarking [ ]

The NRC staff reviewed the LOFT tests that were originally benchmarked using S-RELAP5 with the COPERNIC FPC as part of the RLBLOCA methodology development. The NRC staff reviewed the revised LOFT input models for the S-RELAP5 system code with both the GALILEO and the COPERNIC FPCs to provide a direct comparison. For each LOFT RLBLOCA test benchmarked the S-RELAP5 coupled with GALILEO FPCs [

] The NRC staff reviewed the details of the benchmarking and LOFT results and determined that the Framatome's methodology to supplement COPERNIC with GALILEO in RLBLOCA methodology is acceptable.

In summary, the NRC staff reviewed the LOFT tests, the test configuration and test results and determined that the S-RELAP5 benchmarking and LOFT RLBLOCA tests [

]

3.5 RLBLOCA SAMPLE PWR PROBLEM WITH GALILEO

This section provides details of a sample problem performed by Framatome for RBLOCA analysis for a Westinghouse 3-loop PWR. This sample problem is similar to the sample problem presented in the approved RLBLOCA evaluation and methodology TR (Appendix B, EMF-2103-P-A, Revision 3) presented to provide representative solutions to the RLBLOCA evaluation. The sample problem uses Framatome fuel with M5 cladding and utilizes the GALILEO code for the fuel calculations with S-RELAP5 and additional rods added to the COPERNIC model. The generic plant is a Westinghouse 3-loop design with dry atmospheric containment, the loop contains three RCPs, three U-tube steam generators, and a pressurizer.

A typical calculation using S-RELAP5 begins with the establishment of a steady-state, initial condition with all loops intact. The input parameters and initial conditions for this steady-state calculation are chosen to reflect plant technical specifications or to match measured data. Following the establishment of an acceptable steady-state condition, the transient calculation is initiated by introducing a break into one of the loops. Table 3-19, "Technical Changes from the Approved RLBLOCA EM Included in the Sample Problem," of Reference 1 lists the technical changes from approved (COPERNIC) RLBLOCA EM in the sample problem. Table 3-20, "3-Loop Westinghouse - Plant Parameter Values and Ranges," of Reference 1 lists 3-loop Westinghouse plant physical parameter, plant operating conditions, and plant parameter values and ranges. Table 3-21, "3-Loop Westinghouse - Statistical Distributions Used for Process Parameters," of Reference 1 lists statistical distributions used for the process parameters such as, [

]

[ ] were performed for the RLBLOCA sample problem. Table 2 below provides comparison of results for the limiting PCT GALILEO hot rod and the corresponding COPERNIC hot rod. The PCT and MLO shows that the ECCS acceptance criteria and GDC-35 for LOOP and metal-water reaction is confirmed. Table 3 below provides comparison of results from sample problem for the rod rupture calculations.

Table 2: Comparison of Results from Sample Problem (Ref. 1)

[ ]

Table 3: Comparison of Results from Sample Problem for the Rod Rupture

[ ]

The NRC staff reviewed the results from the sample problem for RLBLOCA for several parameters in the acceptance criteria for LBLOCA such as PCT, oxidation, hydrogen formation, and core cooling. Figure 3-52, "Comparison of GALILEO and COPERNIC PCT Independent of Elevation for Fresh UO_2 Rod – Case 018," of Reference 1 shows PCT independent of elevation and [ ] Figure 3-53, "Comparison of GALILEO and COPERNIC Peak Node Surface Temperature for Fresh UO2 Rod – Case 018," of Reference 1 compares the cladding temperature at the PCT node [ ], while Figure 3-54, "Comparison of GALILEO and COPERNIC Fuel Centerline Temperature for Fresh UO_2 Rod – Case 018," of Reference 1 compares the fuel centerline temperature at the same elevation. Figure 3-55, "Comparison of GALILEO and COPERNIC Rod Pressure for Fresh UO_2 Rod – Case 018," of Reference 1 compares the rod internal pressure (RIP). Comparisons for results are also made for burned UO_2 fuel and fresh fuel with Gadolinia (Gd_2O_3) for PCT, fuel centerline temperatures, and RIP. The cladding temperatures and fuel [ ]

The NRC staff reviewed the results from the sample problem and confirmed that the cladding temperatures, fuel centerline temperatures, and RIP [ ] This comparison of results from the sample problem demonstrates that [ ] Therefore, the NRC staff has determined that the supplement of COERNIC with GALILEO code for RLBLOCA analysis for PWR is acceptable because [

] Therefore, the NRC staff has determined that the supplement of COPERNIC FPC with GALILEO will ensure compliance with LBLOCA regulations, 10 CFR 50.46 and GDC 35 as well as the guidance of applicable SRP Sections, SRP 6.3 for ECCS performance analysis.

3.6 GALILEO IMPLEMENTATION IN THE SBLOCA EM

This section details the processes by which the GALILEO code is implemented in SBLOCA analysis replacing the use of RODEX2 FPC. The EM requirements for approved SBLOCA are described in References 6 and 11. The postulated SBLOCA is defined as a break in the PWR primary coolant system pressure boundary having a break area equal to or less than 10 percent of the cross sectional area of the cold leg or vessel inlet pipes. The approved SBLOCA EM (Ref. 6 and Ref. 11) clad deformation and rupture model are specific to the cladding type but are implemented in S-RELAP5. The overall evaluation model remains the same, but the RODEX2 FPC is supplemented with GALILEO.

The approved SBLOCA EM uses RODEX2 coupled with SRELAP5. The supplemental EM (ANP-10349P) supplements RODEX2 with the approved GALILEO code in SBLOCA analysis. The use of RODEX2 in the process is similar to the GALILEO implementation in S-RELAP5 described in Section 3.2 of this SE. The major difference is [

] described in Section 3.2 of this SE.

3.6.1 Assessment of GALILEO Implementation in SBLOCA Methodology

The evaluation model changes in supplemental SBLOCA methodology is described in Sections 4.4, "Assessment Data Base Summary," and 4.5, "Evaluation Model Description," of Reference 1 and supplemented by the response to RAI 2. The NRC staff reviewed the information provided in the TR and RAI response as summarize in this section. The SBLOCA analysis consists of a series of break spectrum, delayed RCP trip, attached piped breaks, and sensitivity calculations. The flow of calculation is identical to the evaluation model using RODEX2 but using GALILEO. One exception is [

] The rest of the calculation is consistent with the base methodology in References 6 and 13. Calculation flow includes three steps:

- An initialization calculation with GALILEO
- S-RELAP5 calculation for overall thermal-hydraulic response of the system
- Additional sensitivity calculations

RODEX2-2A/GALILEO calculations are used to set up the initial conditions for the S-RELAP5 calculations. The break spectrum calculations are performed [

] For plants with [

] As part of the implementation of the GALILEO FPC, a [

]

The NRC staff reviewed Framatome's technical evaluation of the cladding thermal response during an SBLOCA transient performed as part of the implementation of the GALILEO fuel rod code. The cladding thermal response was found affected [

] Sensitivity studies were initiated for SBLOCA using the input model. The NRC staff reviewed the sensitivity studies performed by Framatome described in the TR, in the response to RAIs as well as in the audited documents [

]

Framatome in a response to RAI 2b provided similarity between the supplement of COPERNIC and RODEX2 with GALILEO in SBLOCA and RLBLOCA, respectively. Both RODEX2 and GALILEO [ ] The NRC staff reviewed the processes and determined that the differences in the S-RELAP5 integration between RODEX2 and GALILEO consist [ ] For RODEX2, [ ] in S-RELAP5/RODEX2. The NRC staff reviewed the entire process of what was done for the SBLOCA and determined that the key input parameters listed in Table 4-4, "GALILEO Key Input Parameters for SBLOCA," of Reference 1 and the fuel design data have been incorporated in to the SBLOCA evaluation model [ ].

3.6.2 S-RELAP5 SBLOCA Model of LOFT Facility (L3-6, L8-1)

The NRC staff reviewed the process by which the Framatome benchmarked the S-RELAP5 code against the LOFT L3-8 and L8-1 tests to justify the S-RELAP5 physical models and modeling techniques to SBLOCAs with the RCPs running. This test simulates a 2.5 percent small break (4 inch equivalent) in the cold leg of a large PWR. During the test, the accumulators, and Low Pressure Injection System (LPIS) were not activated. The High Pressure Injection System (HPIS) provides safety injection (SI) into the downcomer. The S-RELAP5 benchmark analysis performed by Framatome demonstrated the code's ability to accurately simulate the overall system response following a 4-inch diameter SBLOCA event in the cold leg with the primary coolant pump running during the blowdown phase.

Table 4-2, "Initial Conditions for Test LOFT L3-6," of Reference 1 compares the S-RELAP5 calculated initial conditions for L3-6 test using either GALILEO or RODEX2 as the FPC with the conditions reached during the experiment. Details of the L3-6 test is provided in Section 4.6.1, "LOFT Small Break Tests L3-6 and LB-1," of Reference 1. The NRC staff has reviewed the documents including those documents during the audit (Ref. 10) and determined that the results from the LOFT tests and their analysis results using GALILEO [

] and the experiments have validated the use of GALILEO as the FPC in the SBLOCA EM. NRC staff finds that S-RELAP5 adequately captures the phenomena experienced during the LOFT L3-6 and L8-1 test sequence. The use of GALILEO as the fuel performance code [ ].

3.6.3 SBLOCA Sample Problem with GALILEO

The NRC staff reviewed a sample problem that simulates the SBLOCA analysis for a CE 2x4-loop PWR. This sample problem provides a comparative evaluation of a representative solution to the SBLOCA evaluation using the approved EM with RODEX2 and the supplemental EM using GALILEO. This sample problem simulates a representative core operating power and peaking factors similar or higher than found in the current operating fleet. The sample problem uses Framatome fuel with M5 cladding and utilizes the GALILEO code for fuel calculations within S-RELAP5. The sample problem plant is a CE 2x4-loop design with [

]

The NRC staff reviewed the inputs, event sequence used in the sample problem and the results obtained from the sample problem. Table 4-6, "SBLOCA Sample Problem Design Inputs," of Reference 1 lists the inputs to the sample problem for the generic power plant. Table 4 below lists a comparison of results of limiting break size from GALILEO and RODEX2.

<u>Table 4: Comparison of Results for the Limiting Break Size from Sample Problem</u>

[ ]

The NRC staff reviewed the results presented in the TR. Figure 4-15, "Comparison of GALILEO and RODEX2 PCT Results," of Reference 1 illustrates the results from the entire spectrum of breaks. Figure 4-16, "Comparison of GALILEO and RODEX2 MLO Results," of Reference 1 illustrates the calculated results for the MLO from the two FPCs and it indicates that [

] Figure 4-17, "Comparison of GALILEO and RODEX2 PCT Independent of Elevation – [ ]" of Reference 1 compares the PCT independent of elevation. Figure 4-19, "Comparison of GALILEO and RODEX2 Fuel Centerline Temperature – [ ]" of Reference 1 compares the fuel centerline temperature at the same location. The cladding temperatures [

]

The NRC staff verified the transient results from the sample problem with the original SBLOCA methodology. The transient results from comparing GALILEO and RODEX2 results of SBLOCA EM show that [

] as implemented in the SBLOCA EMF-2328 EM (Refs. 6 and 11). The NRC staff confirmed that [

] These results demonstrate that [

] The NRC staff reviewed the results as presented in Reference 1 and the documents during audit and determined that the use of GALILEO instead of RODEX2 for SBLOCA EM is acceptable based on the behavior of SBLOCA parameters as prescribed in its acceptance criteria. The NRC staff determined that the SBLOCA EM with GALILEO continues to comply with 10 CFR 50.46 acceptance criteria and the guidance as prescribed by SRP 6.3 for ECCS performance analysis.

Comparison of SBLOCA Results Using RODEX2 and GALILEO

The NRC staff reviewed the results as presented in Reference 1 and the documents during audit and determined that the use of GALILEO instead of RODEX2 for SBLOCA EM is an acceptable based on the behavior of SBLOCA parameters as prescribed in its acceptance criteria. The NRC staff determined that the SBLOCA EM with GALILEO continues to comply with 10 CFR 50.46 acceptance criteria and the guidance as prescribed by SRP 6.3 for ECCS performance analysis.

4.0 LIMITATIONS AND CONDITIONS

The demonstrated range of applicability of the methodology, specifically RLBLOCA and SBLOCA (EMF-2103 Rev 3, and EMF-2328 Rev 0 and Supplement 1) and applicable range (not related to the thermo-mechanical method) of applicability of GALILEO topical report (ANP-10323P) shall be implemented in the supplement EM (ANP-10349).

5.0 CONCLUSION

ANP-10349P describes the implementation of the GALILEO FPC in the SBLOCA and RLBLOCA methodologies for Westinghouse and CE PWR designs. This TR supplements the approved EMs and presents the implementation of the GALILEO FPC in S-RELAP5 and the LOCA EMs applicable to Westinghouse and CE plant designs. In addition, the GALILEO methodology does not replace the COPERNIC and RODEX2 methodologies, which continue to be acceptable. The NRC staff reviewed the results from the supplemental evaluation model (ANP-10349P) for both RLBLOCA and SBLOCA in which Framatome supplemented the COPERNIC FPC and RODEX2 FPC with GALILEO FPC along with the respective LOFT test results and the sample problems. The NRC staff determined that GALILEO FPC is an acceptable supplement for COPERNIC FPC for RLBLOCA EM, and GALILEO FPC code is an acceptable supplement for RODEX2 FPC for SBLOCA EM. This determination is based on confirmatory benchmark calculations using LOFTs and sample problems for both RLBLOCA and SBLOCA. The LOFT tests and sample problems [

]

The NRC staff has also determined that the RLBLOCA and SBLOCA supplemental evaluation models (ANP-10349) satisfies the guidance in SRP sections 6.3, 15.6.5, and requirements in GDC 35 for 1) peak cladding temperatures, 2) maximum oxidation, 3) maximum hydrogen generation, 4) coolable geometry, 5) long term cooling, and 6) decay heat removal. The LOFT test involves input with LOOP, thereby complying with GDC 35 requirement.

The NRC staff confirmed that the results from the RLBLOCA and SBLOCA supplemental evaluation models (ANP-10349) are reasonable and sufficiently close between each other. The NRC staff's determination is based primarily on direct comparisons against experimental LOFT data. However, the NRC staff is aware of the fact that code-to-code comparisons are valuable to supplement experimental data benchmarks but cannot replace them completely in future submittals. Therefore, the staff has determined that the supplemental evaluation model is acceptable for licensing application subject to the limitation condition specified in Section 4.0 of this SE.

The NRC staff requires that Framatome shall publish the accepted version of ANP-10349P as a supplemental document to the approved final versions of both RLBLOCA TR (EMF-2103) and SBLOCA TR (EMF-2328).

6.0 REFERENCES

1. Submittal of ANP-10349P, Revision 0, "GALLEO Implementation in LOCA Methods," Framatome, Inc., October 2020 (ADAMS Package Accession No. ML20290A661).

2. Publication of ANP-10323(P)(A), Revision 1, "GALILEO Fuel Thermal-Mechanical Methodology for Pressurized Water Reactors," Framatome, Inc., December 2020 (ADAMS Package Accession No. ML21005A028).

3. BAW-10231-P-A, Revision 1, "COPERNIC Fuel Rod Design Computer Code," Framatome ANP, January 2004 (ADAMS Package Accession No. ML042930233).
4. XN-NF-81-58(P)(A), Revision 2, Supplements 1 and 2, "RODEX2 Fuel Rod Thermal-Mechanical Response Evaluation Model," Exxon Nuclear Company, 1984.

5. EMF-2103(P)(A), Revision 3, "Realistic Large Break LOCA Methodology for Pressurized Water Reactors," AREVA, September 2016 (ADAMS Package Accession No. ML16286A579).

6. EMF-2328(P)(A), Revision 0, Supplement 1 (P)(A), Revision 0, "PWR Small Break LOCA Evaluation Model, S-RELAP5 Based," AREVA, December 2016 (ADAMS Package Accession No. ML16356A396).

7. US NRC Letter from Dennis Morey to Gary Peters (Framatome), "February 10 - 12, 2021, Regulatory Audit Plan for Framatome INC. Topical Report, ANP-10349P, Revision 0, 'GALILEO Implementation in LOCA Methods,'" February 10, 2021 (ADAMS Package Accession No. ML21035A067).

8. USNRC Regulatory audit report for ANP-10349P, "GALILEO Implementation in LOCA Methods" (ADAMS Accession No. ML21070A314).

9. USNRC Letter from Ngola Otto to Gary Peters, "Request for Additional Information Regarding Framatome Topical Report, ANP-10349P, Revision 0, "GALILEO Implementation in in LOCA Methods" March 23, 2021 (ADAMS Package Accession No. ML21070A309).

10. Letter NRC:21:014 from Gary Peters (Framatome) to USNRC, "Response to Request for Additional Information Regarding ANP-10349P Revision 0, "GALILEO Implementation in LOCA Methods," April 23, 2021 (ADAMS Package Accession No. ML21119A140).

11. EMF-2328(P)(A), Revision 0, "PWR Small Break LOCA Evaluation Model, S-RELAP5 Based," March 2001 (ADAMS Package Accession No. ML011410426).

Principal Contributor: Mathew Panicker

Date: November 15, 2021

framatome

GALILEO Implementation in LOCA Methods

ANP-10349NP
Revision 0

Topical Report

October 2020

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
AFM	Advanced Fuel Methods
CDF	Cumulative Distribution Function
CE	Combustion Engineering
CP	Cathcart-Pawel
CSAU	Code Scaling, Applicability, and Uncertainty
CWO	Core-Wide Oxidation
EATF	Enhanced Accident Tolerant Fuel
ECC	Emergency Core Cooling
ECCS	ECC System
EM	Evaluation Model
EMDAP	Evaluation Model Development and Assessment Process
FPC	Fuel Performance Code
IET	Integral Effects Test
LHGR	Linear Heat Generation Rate
LOCA	Loss-of-Coolant Accident
LOFT	Loss-of-Fluid Test
MLO	Maximum Local Oxidation
NRC	U.S. Nuclear Regulatory Commission
PCT	Peak Cladding Temperature
PH	Power History
PIRT	Phenomena Identification and Ranking Table
PWR	Pressurized Water Reactor
PZR	Pressurizer

Acronym	Definition
Q-Q	Quantile-Quantile
RLBLOCA	Realistic Large Break LOCA
SBLOCA	Small Break LOCA
SG	Steam Generator
SIT	Safety Injection Tank
SRM	Swelling and Rupture Model
SRR	Swelling, Rupture and Relocation
W	Westinghouse Electric Company

ABSTRACT

Framatome Inc. currently has NRC approved topical reports for small-break and large-break loss-of-coolant accident (LOCA) methodologies for Westinghouse (W) 3- and 4-loop designs and Combustion Engineering (CE) 2x4 designed Pressurized Water Reactors (PWR). The realistic large-break LOCA (RLBLOCA) evaluation model (EM) uses a best-estimate approach based on statistical sampling of uncertainty contributors and propagation of uncertainty to determine the expected peak cladding temperature (PCT), Maximum Local Oxidation (MLO) and total Core-Wide Oxidation (CWO) response. The RLBLOCA EM is patterned after the Code Scaling, Applicability, and Uncertainty (CSAU) methodology and follows the recommendations of Regulatory Guide 1.203, Evaluation Model Development and Assessment Process (EMDAP). The small-break LOCA (SBLOCA) EM uses a deterministic approach based on the requirements of 10 CFR 50 Appendix K to determine the expected PCT, MLO and CWO response.

The LOCA EMs for W and CE designed PWRs use S-RELAP5 as system thermal hydraulics code, which embeds a kernel of a Fuel Performance Code (FPC) such as COPERNIC for RLBLOCA or RODEX2 for SBLOCA. The stand-alone FPC is used to provide initialization conditions for S-RELAP5. The present topical report supplements the approved EMs and implements the GALILEO FPC in S-RELAP5. The topical report presents the applicable EM changes and includes code benchmarks of relevant LOFT SBLOCA and LBLOCA tests. The report also presents results from sample problems for both methods and compares the results for the relevant figures of merit to the current EMs.

The report demonstrates that the benchmarks are unaffected and that the change in FPC has negligible impact on the calculated figures of merit for both the RLBLOCA and SBLOCA evaluation models. This report concludes that the GALILEO implementation in the LOCA methods is acceptable for licensing applications.

1.0 INTRODUCTION

This report describes the implementation of the GALILEO FPC in the SBLOCA and RLBLOCA methodologies for W and CE design PWRs with recirculation (U-tube) steam generators, fuel assembly lengths of 14 feet or less, and ECCS injection to the cold legs. The present report supplements the approved Evaluation Models for RLBLOCA (Reference 1) and SBLOCA (References 3 and 4) and is adding GALILEO functionality to their current capabilities.

The current approved RLBLOCA EM is a best-estimate plus uncertainty methodology which has been reviewed and approved by the NRC in 2016 (Reference 1). The approved EM is an evolution of the previous approved version of the EM, Revision 0 (Reference 2), which has been reviewed and approved by the NRC in 2003. Between 2008 and up to the approval of Revision 3 of the RLBLOCA EM, interim submittals were based on the so-called Revision 0 Transition Package.

The current approved SBLOCA EM (Reference 3) is a 10 CFR 50.46 Appendix K-based model that has been reviewed and approved by the NRC in 2001. $M5_{Framatome}$ properties were incorporated in the SBLOCA EM in Reference 24 which was reviewed and approved in 2002. The SBLOCA EM was recently supplemented through the EM changes described in Reference 4, which were reviewed and approved by the NRC in 2016.

The RLBLOCA and SBLOCA EMs are mature and well-tested methodologies that have been used for numerous LOCA analyses which support the licensing basis of over twenty nuclear units in the U.S. and the world.

The present topical report supplements the approved EMs and presents the implementation of the GALILEO FPC in S-RELAP5 and the LOCA EMs applicable to W and CE plant designs. GALILEO is a best-estimate FPC (Reference 7) and its implementation supports development plans for future Advanced Fuel Methods (AFM) and Enhanced Accident Tolerant Fuel (EATF).There is no change associated with the GALILEO implementation described in this report in the scope of the phenomena addressed by the approved EMs. The approved EMs for RLBLOCA (Reference 1) and SBLOCA (References 3 and 4) remain applicable on their own as currently approved. All the limitations and conditions currently applicable the approved RLBLOCA and SBLOCA EMs remain applicable to the supplemented EMs.

Section 2.0 provides an overview of the GALILEO FPC implementation in S-RELAP5 with references to the models used and a description of the coupling scheme between GALILEO and the S-RELAP5 code.

Section 3.0 describes the specific implementation of GALILEO in the RLBLOCA EM, including a sample problem application. The approved RLBLOCA EM is based on EMDAP and the treatment of the EM updates is reflected in the structure and content of this section.

Section 4.0 presents the specific implementation of GALILEO in the SBLOCA EM, including a sample problem application. The structure of this section is similar to the previous one, but the treatment is specific to an Appendix K-type method.

This report concludes that the GALILEO implementation in the LOCA methods is acceptable for licensing applications. This is supported by:

- GALILEO is an acceptable FPC (Reference 7)
- Assessments against benchmarks show good results
- Comparisons to current approved methods show good agreement

2.0 GALILEO IMPLEMENTATION IN S-RELAP5

S-RELAP5 is a RELAP5-based thermal-hydraulic system code used for performing LOCA and non-LOCA analyses. A key to a LOCA analysis is the model used for calculating fuel rod performance. In particular, the initial operating temperature of the fuel pellets (stored energy), the internal fuel rod gas pressure, and the transient gap conductance are significant parameters which affect the calculated PCT.
Depending on the specific PWR LOCA methodology being used, S-RELAP5 permits the optional use of fuel rod models based on the fuel rod analysis codes shown in Table 2-1.

2.1 *General Features of Fuel Rod Model Implementation in S-RELAP5*

The physical phenomena modeled in each of the fuel rod codes shown in Table 2-1 can generally be divided into two categories:

[ ]

Based on these categories of phenomena, the individual fuel rod codes are used in

[ ]

[ ]

The above implementation provides a treatment of the thermal effect of fuel rods which is consistent with both the overall S-RELAP5 thermal solution and with the thermal-mechanical models in the individual fuel rod model being used.

The GALILEO code models are summarized in Section 3.3.3 of Reference 7 with full details available in Reference 8.

2.2 *GALILEO Coupling with S-RELAP5*

Table 2-1
Fuel Rod Models for PWR LOCA Available in S-RELAP5

Fuel Rod Code	Intended Methodology	References
RODEX2	PWR SBLOCA	3, 4
COPERNIC	PWR RLBLOCA Rev. 3	1
GALILEO	PWR SBLOCA, PWR RLBLOCA Rev. 3	Present TR

3.0 GALILEO IMPLEMENTATION IN THE RLBLOCA EM

The present RLBLOCA EM development adds GALILEO functionality to the approved EM for improved scale of application and support for future development. GALILEO is a best-estimate FPC (Reference 7) for application to PWR.

3.1 *Regulatory Requirements Summary*

The regulatory requirements for the approved RLBLOCA EM are described in detail in Section 3.0 of Reference 1. These requirements remain unchanged for the supplemented RLBLOCA EM which implements GALILEO as FPC.

3.2 *Scenario Identification*

The scenario identification, including analysis purpose, transient class and power plant class, as well as the figures of merit are extensively described for the approved RLBLOCA EM in Section 4.0 of Reference 1. The supplemented RLBLOCA EM is applicable to the same transient scenario and PWR models and retains the same figures of merit as the approved RLBLOCA EM.

3.3 *Evaluation Model Requirements*

The EM requirements for the approved RLBLOCA EM are described in Section 5.0 of Reference 1 and the PIRT process detailed therein provides the application envelope for the EM by identifying and establishing the importance of the constituent phenomena, processes and key parameters within the envelope.

The PIRT for the approved EM is provided in Table 5-1 of Reference 1. In this table, each phenomenon is given a ranking, where importance is proportional to the numerical value (e.g., 9 = extreme importance and 1 = least importance). High rankings indicate the important phenomena that should be simulated by the RLBLOCA EM. Those phenomena with a ranking of 5 or higher are classified as important phenomena (Reference 1, Section 5.2).

The following definitions apply to the PIRT:

1. Blowdown (BD): The blowdown phase of the LOCA is defined as the time period from initiation of the break until flow from the accumulators or SIT begins.
2. Refill (RFL): The refill phase of the LOCA begins when the accumulators or SIT begin injecting and continues until the mixture level in the vessel refills the lower plenum and flow into the heated core region begins.
3. Reflood (RFD): The reflood phase of the transient begins when the lower plenum fills and ECC begins flowing into the bottom of the active core and continues until the temperature transient throughout the core has been terminated. At that time, the LOCA stored energy and decay heat are being removed and the LOCA has been reduced to an issue of maintaining long-term cooling.

The original PIRT table has been examined to identify the phenomena that are relevant to the supplemented EM changes. [

]

[

]

Consequently, the rankings of the important phenomena [

] presented in Table 3-1 stay unchanged. [

]

3.4 *Assessment Data Base Summary*

Table 3-1 summarizes the fuel rod key phenomena present in a LBLOCA. All these phenomena are accounted for either statistically or with a bias, and a justification for the selected treatment is provided. The approved EM validation matrix includes all of the phenomena or processes selected for validation, and is presented in Table 6-1 of Reference 1. The phenomena identified in Table 3-1 are analyzed from the standpoint of the treatment within the approved EM. The treatment is summarized for all PIRT parameters, of which the relevant section [ ] is reproduced below in Table 3-2. Where an item ranked 5 or higher is not included in the validation matrix, an explanation, sensitivity study or other, is provided in Table 3-2 to justify the exclusion.

3.4.1 EM Changes Roadmap and Objectives for Assessment Data Base

[

]

The considerations for establishing the assessment matrix are listed in Section 6.1 of Reference 1. The approved RLBLOCA EM has been validated using a database that met the required standards and objectives. The discussion above focuses the validation objectives on the EM features that are directly affected by the FPC change. This leads to two major objectives for the assessment base:

[

]

3.4.2 Assessment Data Base

The approved RLBLOCA EM assessment matrix is provided in Table 6-2 of Reference 1. [

] Taking into account these considerations, the experimental database to be used for the supplemented EM is provided below in Table 3-3.

3.5 *Evaluation Model Description*

[

]

The description provided in Section 9.0 of Reference 1 remains applicable to the supplemented RLBLOCA EM. Changes to the EM due to the GALILEO implementation as FPC are presented below.

3.5.1 GALILEO Uncertainties

[ ]

[ ]

3.5.2 Methodology Treatment of PIRT Phenomena

[ ] This section provides a discussion of these treatments and details any changes that are made to the approved RLBLOCA EM stemming from the implementation of the GALILEO FPC.

3.5.2.1 [ ]

[ ]

[ ]

3.5.2.2 [ ]

[ ]

[ ]

3.5.2.3 [ ]

[ ]

3.5.2.4 [ ]

[ ]

3.5.2.5 [ ]

[ ]

3.5.2.6 [ ]

[ ]

3.6 *Assessment Results*

3.6.1 LOFT Large Break Tests L2-3, L2-5, LP-02-6 and LP-LB-1

3.6.1.1 Introduction

As part of the approved RLBLOCA EM (Reference 1), the Loss-Of-Fluid-Test (LOFT) integral effect tests L2-3, L2-5, LP-02-06, and LP-LB-1 were simulated using the S-RELAP5 system code coupled with the COPERNIC fuel performance code and the results are documented in Section 8.3 of Reference 1. These four LOFT tests were identified as part of the assessment base for the supplemented RLBLOCA EM (see Section 3.4.2) and are benchmarked using the coupled S-RELAP5/GALILEO code to validate the applicability of its use in the supplemented RLBLOCA EM.

[ ]

A set of plots of the same system parameters and the fuel rod temperatures given in Section 8.3.1 of Reference 1 are made using the S-RELAP5/COPERNIC and S-RELAP5/GALILEO runs. From these results, the following conclusions are made:

The simulations of these four LOFT tests are discussed in detail in following sections.

3.6.1.2 Facility Description

LOFT was an NRC-sponsored nuclear test facility designed to simulate the nuclear and thermal-hydraulic phenomena that take place in a PWR LBLOCA. The LOFT facility was a 50 MWt experimental PWR designed to simulate the system response of a 4-loop Westinghouse PWR during a hypothetical LBLOCA. The facility included five major subsystems; an intact loop, a broken loop, a reactor vessel, an emergency core cooling system, and a blowdown suppression system. The LOFT facility was instrumented so that system parameters could be measured during the tests. A complete detailed discussion of the LOFT facility and an instrumentation description are found in Section 8.3.1.3.1 in Reference 1. The major components and test instrument locations in the system are shown in Table 3-4.

3.6.1.3 LOFT Large Break Tests

Between 1976 and 1985, 50 LOFT tests were performed. The LOFT facility was designed primarily for performing LBLOCA tests. However, only five tests; L2-2, L2-3, L2-5, LP-02-6 (L2-6), and LP-LB-1 (LB-1), were LBLOCA tests with a heated nuclear core. The first three LBLOCA tests were sponsored by the NRC and the last two were conducted under the auspices of the OECD sponsored by an international consortium. Table 3-4 lists the characteristics and parameters of the LOFT nuclear LBLOCA Tests. A detailed description of the Tests L2-3, L2-5, LP-02-6, and LP-LB-1 is given in section 8.3.1.3.2 of Reference 1.

3.6.1.4 Input Model Development

The computer codes used to perform the LOFT test assessment calculations were COPERNIC and S-RELAP5. COPERNIC is the Framatome Inc.'s best-estimate fuel rod thermal-mechanical behavior analysis code used in Reference 1. [

]

Recently, Framatome Inc. decided to add an option to use the currently developed advanced best-estimate fuel rod thermal-mechanical behavior analysis code GALILEO to use in the approved RLBLOCA Revision 3 of the methodology. [

]

[

]

3.6.1.4.1 Revised COPERNIC and S-RELAP5 Input Models

[

]

3.6.1.4.2 GALILEO and S-RELAP5 Input Models

GALILEO Input Models

GALILEO fuel rod input models are developed starting from the COPERNIC input models discussed in Section 3.6.1.4.1 to meet the GALILEO input requirements. [

]

S-RELAP5 Input Models

The S-RELAP5 steady-state and transient input models are developed from the corresponding input models described in Section 3.6.1.4.1 [

]

3.6.1.5 Results

The following sections discuss the steady-state and the transient benchmark results of the LOFT Tests L2-3, L2-5, LP-02-6, and LP-LB-1.

3.6.1.5.1 LOFT Test L2-3

Steady-state Results

A steady-state initialization calculation was made to obtain the desired initial conditions for the transient simulation. Table 3-5 compares the steady-state conditions calculated using S-RELAP5 coupled with either GALILEO or COPERNIC and the measured data at the break initiation. [

]

Transient Results

Table 3-6 gives the event set points and boundary conditions that have an impact after the start of the transient portion of the Test L2-3 simulation. Table 3-7 compares the measured time of the events with those calculated by S-RELAP5/GALILEO and with S-RELAP5/COPERNIC codes. [

]

The following figures show the transient response of several primary system parameters:

- Figure 3-7 shows the reactor vessel upper plenum pressure.

- Figure 3-8 shows the PZR collapsed liquid level.
- Figure 3-9 shows the broken loop cold leg (BLCL) average fluid density.
- Figure 3-10 shows the BLCL mass flow rate.
- Figure 3-11 shows the fluid temperature in the UP.
- Figure 3-12 shows the accumulator collapsed liquid level.
- Figure 3-13 shows the mass flow rates from the low pressure safety injection system.

[ ]

Figure 3-14 shows the central fuel assembly instrumented fuel rod locations and the S-RELAP5 axial fuel rod temperature calculation locations. Figure 3-15 shows the fuel rod cladding temperatures at the 26 inch elevation. From this figure, the following conclusions are made:

[ ]

Similar observations are also made from the temperature plots at other elevations shown in the figures in Section 8.3.1.5 of Reference 1.

Figure 3-16 shows a comparison of the peak cladding temperature vs. core elevation.

[ ]

3.6.1.5.2 LOFT Test L2-5

Steady-state Results

A steady-state initialization calculation was conducted to obtain the desired initial conditions for the transient simulation. Table 3-8 compares the steady-state conditions calculated using S-RELAP5 coupled with either GALILEO or COPERNIC and the measure data at the break initiation. [ ]

Transient Results

Table 3-9 gives the event set points and boundary conditions that have an impact after the start of the transient portion of the Test L2-5 simulation. Table 3-10 compares the measured time of the events with those calculated by S-RELAP5/GALILEO and with S-RELAP5/COPERNIC codes. [ ]

The following figures show the transient response of several primary system parameters:

- Figure 3-17 shows the reactor vessel upper plenum pressure.
- Figure 3-18 shows the PZR collapsed liquid level.
- Figure 3-19 shows the broken loop cold leg (BLCL) average fluid density.
- Figure 3-20 shows the BLCL mass flow rate.
- Figure 3-21 shows the fluid temperature in the UP.
- Figure 3-22 shows the accumulator pressure.
- Figure 3-23 shows the mass flow rates from the low pressure safety injection system.

[ ]

Figure 3-24 shows the central fuel assembly instrumented fuel rod locations and the S-RELAP5 axial fuel rod temperature calculation locations. Figure 3-25 and Figure 3-26 show the fuel rod cladding temperatures at the 26-inch elevation and fuel rod centerline temperature at the 27-inch elevation, respectively. From these figures, the following conclusions are made:

[ ]

Similar observations are also made from the temperature plots at other elevations shown in the figures in Section 8.3.1.6 of Reference 1.

Figure 3-27 shows the comparisons of the peak cladding temperatures vs. core elevation. [

]

3.6.1.5.3 LOFT Test LP-02-06

Steady-state Results

A steady-state initialization calculation was to obtain the desired initial conditions for the transient simulation. Table 3-11 compares the steady-state conditions calculated using S-RELAP5 coupled with either GALILEO or COPERNIC and the measure data at the break initiation. [

]

Transient Results

Table 3-12 gives the event set points and boundary conditions that have an impact after the start of the transient portion of the Test LP-02-06 simulation. Table 3-13 compares the measured time of the events with those calculated by S-RELAP5/GALILEO and with S-RELAP5/COPERNIC codes. [

]

The following figures show the transient response of several primary system parameters:

- Figure 3-28 shows the reactor vessel upper plenum pressure.
- Figure 3-29 shows the PZR collapsed liquid level.
- Figure 3-30 shows the broken loop cold leg (BLCL) average fluid density.
- Figure 3-31 shows the BLCL mass flow rate.
- Figure 3-32 shows the fluid temperature in the UP.
- Figure 3-33 shows the accumulator collapsed liquid level.
- Figure 3-34 shows the mass flow rates from the low pressure safety injection system.

[ ]

Figure 3-35 shows the central fuel assembly instrumented fuel rod locations and the S-RELAP5 axial fuel rod temperature calculation locations. Figure 3-36 and Figure 3-37 show the fuel rod cladding temperatures at the 26-inch elevation and fuel rod centerline temperature at the 27-inch elevation, respectively. From these figures, the following conclusions are made:

[ ]

[ ]

Similar observations are also made from the temperature plots at other elevations shown in the figures in Section 8.3.1.7 of Reference 1.

Figure 3-38 shows the comparisons of the peak cladding temperatures vs. core elevation. [

]

3.6.1.5.4 LOFT Test LP-LB-1

Steady-state Results

A steady-state initialization calculation was made to obtain the desired initial conditions for the transient simulation. Table 3-14 compares the steady-state conditions calculated using S-RELAP5 coupled with either GALILEO or COPERNIC and the measure data at the break initiation. [

]

Transient Results

Table 3-15 gives the event set points and boundary conditions that have an impact after the start of the transient portion of the Test LP-LB-1 simulation. Table 3-16 compares the measured time of the events with those calculated by S-RELAP5/GALILEO and with S-RELAP5/COPERNIC codes. [

]

The following figures show the transient response of several primary system parameters:

- Figure 3-39 shows the reactor vessel upper plenum pressure.
- Figure 3-40 shows the PZR collapsed liquid level. The PZR liquid level data probe failed after about 4 seconds and the instrument recorded 0.0 m (see page 8.3-94 in Reference 1).
- Figure 3-41 shows the broken loop cold leg (BLCL) average fluid density.
- Figure 3-42 shows the BLCL mass flow rate.
- Figure 3-43 shows the fluid temperature in the UP.
- Figure 3-44 shows the accumulator collapsed liquid level.
- Figure 3-45 shows the mass flow rates from the low pressure safety injection system.

[

]

Figure 3-46 shows the central fuel assembly instrumented fuel rod locations and the S-RELAP5 axial fuel rod temperature calculation locations. Figure 3-47 and Figure 3-48 show the fuel rod cladding temperatures at the 27-inch elevation and fuel rod centerline temperature at the 27-inch elevation, respectively. From these figures, the following conclusions are made:

[ ]

Similar observations are also made from the temperature plots at other elevations shown in the figures in Section 8.3.1.8 of Reference 1.

Figure 3-49 shows the comparisons of the peak cladding temperatures vs. core elevation. [ ]

3.6.1.6 Conclusions

The LOFT LBLOCA integral tests L2-3, L2-5, LP-02-6, and LP-LB-1 are simulated using the S-RELAP5 system code coupled with either the GALILEO or the COPERNIC fuel performance code. These tests were originally benchmarked using S-RELAP5 with the COPERNIC fuel performance code as part of the RLBLOCA methodology development and the results were documented in Section 8.3.1 of Reference 1. [

] The revised LOFT input models are simulated using the S-RELAP5 system code with both the GALILEO and the COPERNIC fuel performance codes in order to provide a direct comparison. From these benchmarks the following conclusions are made:

[

]

[ ]

3.7 *Evaluation Model Implementation*

3.7.1 Evaluation Model Implementation Changes

This section provides the limited changes identified in the EM implementation for the application of GALILEO in the RLBLOCA EM. Changes related to the EM implementation are mostly confined to Appendix A of Reference 1. The changes to be made need to reflect the EM changes identified in Section 3.5, in particular [ ]

The guidance provided for FPC input development also needs to be updated in order to address GALILEO input.

[ ]

3.7.1.1 [ ]

[ ]

3.7.1.2 Guidelines for GALILEO Input for RLBLOCA

This section provides guidance for developing GALILEO input for use in RLBLOCA analyses. [ ]

[ ]

3.7.1.2.1 Physical Models

3.7.1.2.2 Material Properties

3.7.1.2.3 Model Coefficients Selected

[ ]

3.7.1.2.4 Fuel Rod Characteristics

[ ]

3.7.1.2.5 Pellet Characteristics

[ ]

3.7.1.2.6 Irradiation History Characteristics

[ ]

3.7.2 RLBLOCA Sample Problem with GALILEO

This section provides a sample problem RLBLOCA analysis for a Westinghouse 3-loop PWR. This sample problem analysis is presented to provide a comparative evaluation of a representative solution to the RLBLOCA evaluation using the approved EM (Reference 1) with COPERNIC (Reference 9) and the supplemented EM using GALILEO (Reference 7). The sample problem is not fully representative of any specific plant. The analysis contains representative core designs for higher operating power and peaking factors similar or higher than found in the current operating fleet. This sample problem is similar to the one presented in Appendix B.2 of Reference 1 but it is slightly different with respect to [

] The application has been reviewed to assure that it offers an accurate representation of the RLBLOCA Revision 3 (Reference 1) evaluation model findings and conclusions.

The sample problem uses Framatome fuel with M5Framatome cladding and utilizes the GALILEO code for fuel calculations within S-RELAP5. Additional COPERNIC rods were added to the model for direct comparison. Discussion of the results shown in the following sections is focused on the comparison of results between GALILEO and COPERNIC under identical system response conditions.

3.7.2.1 Description of the Sample Problem

This sample RLBLOCA analysis was performed in accordance with the NRC-approved methodology described in Reference 1 with the exceptions noted below. The plant is a Westinghouse 3-loop design with dry atmospheric containment. The loops contain three RCPs, three U-tube steam generators and a pressurizer. [

]

The analysis is focused on the comparison of the results obtained with COPERNIC, the approved FPC included in the EM, and its alternative, GALILEO.

3.7.2.1.1 Description of Analytical Models

The NRC-approved RLBLOCA methodology is documented in Reference 1 and is based on the use of COPERNIC and S-RELAP5 computer codes. The present Topical Report incorporates GALILEO (Reference 7) in the RLBLOCA EM, [ ] This analysis was performed using S-RELAP5, GALILEO and COPERNIC.

[ ]

The differences from the approved EM in Reference 1 which were included in this analysis are summarized in Table 3-19. The technical upgrades identified in Table 3-19 are an integral part of the supplemented RLBLOCA EM.

The analysis workflow follows the requirements of Reference 1 and is summarized below:

[

]

3.7.2.2 Comparison of RLBLOCA Results Using COPERNIC and GALILEO

[

]

A comparison of the results for the limiting PCT GALILEO hot rod and the corresponding COPERNIC hot rod for the demonstration case is provided in Table 3-23 while Table 3-24 provides a comparison of the calculated rupture results for the same case.

A global illustration of the results from the entire set of 243 cases is provided in

[

]

Similar results are obtained for the total MLO, as illustrated in Figure 3-51, [

]

The demonstration case selected in the GALILEO sample problem [

]

The following figures compare several parameters calculated by GALILEO and COPERNIC for the [

]

The following set of figures compares several parameters calculated by GALILEO and COPERNIC for the [

]

The following set of figures compares several parameters calculated by GALILEO and COPERNIC for the [

]

The last set of figures compares several parameters calculated by GALILEO and COPERNIC for the [

]

3.7.2.3 Conclusions

[

]

Table 3-1
Phenomena Identification and Ranking Table for EM Changes to PWR RLBLOCA

[ ]

Table 3-2
Validation Needs for Important PIRT Entries for EM Changes to RLBLOCA EM

[ ]

Table 3-3
Assessment Matrix Tests and Phenomena Addressed in the Supplemented RLBLOCA EM

[ ]

Table 3-4
LOFT Nuclear Large Break Test Parameters

Test	Power (MWt)	MLHGR (KW/ft)	Pump Operation	Fuel Pressurized	ECC			PCT (K)
					HPIS	LPIS	Accum	
L2-3 - Similar to L2-2, with higher power and increased LHGR.	36	11.9	On	No	2/3	1/2	3/4	914
L2-5 - Similar to L2-3, with pumps turned off and decoupled from their external fly-wheels within 1 s, US Appendix K ECC with 58% L2-3 HPIS	36	12.2	Off[1]	Yes	1/3	1/2	3/4	1078
LP-02-6 - Similar to L2-5, with pumps turned off but initial coastdown with external flywheels, US Appendix K ECC, increased core power and MLHGR.	46	14.9	Off[2]	Yes	1/3	1/2	3/4	1077
LP-LB-1 - Similar to LP-02-6, with pump turned off and decoupled from their external flywheels within 1 s, UK minimum safeguards ECC, and slightly increased core power and MLHGR.	49.3	15.8	Off[1]	No	0/3	1/2	2/4	1256

[1] Atypical rapid pump coastdown
[2] Normal pump coastdown

Table 3-5
Comparison of S-RELAP5 and LOFT L2-3 Steady-State Conditions

Parameter	S-RELAP5	Test L2-3 (Reference 10, Table 1)
Core Power (MWt)		36.7 ± 1
Hot Leg Pressure (Intact) (MPa)		15.06 ± 0.03
Hot Leg Temperature (Intact) (K)		592.9 ± 3
Cold Leg Temperature (Intact) (K)		560.7 ± 3
Mass Flow Rate (kg/s)		199.8 ± 6.3
Pressurizer Level (m)		1.19 ± 0.01
Steam Generator Secondary Pressure (MPa)		6.17 ± 0.08
Steam Generator Secondary Level (m)		3.11 ± 0.025
Steam Flow Rate (kg/s)		19.5 ± 0.4
Feedwater Flow Rate (kg/s)		not specified
Feedwater Temperature (K)		not specified

Table 3-6
Event Setpoints and Boundary Conditions for Simulation of LOFT Test L2-3

Parameter	Value (Reference 1, Table 8.3-3)
Test Initiation (s)	0.00
Reactor Scram Signal (Hot Leg Pressure) (MPa)	14.19
Reactor Scram Signal (time) (s)	0.103
HPIS Initiation (s)	14
LPIS Initiation (s)	29
Accumulator Nitrogen Volume (m^3)	0.84
Effective Accumulator Liquid Volume (m^3)	1.32
Accumulator Liquid Level (m)	2.10
Accumulator Standpipe Position (m)	1.12
Accumulator Pressure (MPa)	4.18
Accumulator Temperature (K)	307.2

Table 3-7
Event Sequence for LOFT Test L2-3

Event	Time (sec)		
	S-RELAP5[3]		Measured Data (Reference 10, Table 2)
	GALILEO	COPERNIC	
Break initiated			0.0
Reactor Scram on HL pressure			0.103
PCT reached			4.95
High-pressure injection initiated			14
Pressurizer emptied			14
Accumulator injection initiated			16
Low-pressure injection initiated			29
Lower plenum refill complete			35
Accumulator injection complete			45
Core quench complete			55

3 [ ]

Table 3-8
Comparison of S-RELAP5 and LOFT L2-5 Steady-State Conditions

Parameter	**S-RELAP5**	**Test L2-5 (Reference 11, Table 2-3)**
Core Power (MWt)	[	36.0 ± 1.2
Hot Leg Pressure (Intact) (MPa)		14.94 ± 0.06
Hot Leg Temperature (Intact) (K)		589.7 ± 1.6
Cold Leg Temperature (Intact) (K)		556.6 ± 4.0
Mass Flow Rate (kg/s)		192.4 ± 7.8
Pressurizer Level (m)		1.14 ± 0.03
Steam Generator Secondary Pressure (MPa)		5.85 ± 0.06
Steam Generator Secondary Level (m)		not specified
Steam Flow Rate (kg/s)		19.1 ± 0.4
Feedwater Flow Rate (kg/s)		not specified
Feedwater Temperature (K)	]	not specified

Table 3-9
Event Setpoints and Boundary Conditions for Simulation of LOFT Test L2-5

Parameter	Value (Reference 1, Table 8.3-6)
Test Initiation (s)	0.00
Reactor Scram Signal (Hot Leg Pressure) (MPa)	14.19
Reactor Scram Signal (time) (s)	0.06
Primary Coolant Pump Trip (s)	1.75
HPIS Initiation (s)	23.90
LPIS Initiation (s)	37.32
Accumulator Nitrogen Volume (m^3)	0.84
Effective Accumulator Liquid Volume (m^3)	1.45
Accumulator Liquid Level (m)	2.10
Accumulator Standpipe Position (m)	0.92
Accumulator Pressure (MPa)	4.29
Accumulator Temperature (K)	303.0

Table 3-10
Event Sequence for LOFT Test L2-5

Event	Time (sec)		
	S-RELAP5[4]		Measured Data
	GALILEO	COPERNIC	(Reference 11, Table 2-1)
Break initiated	[		0.0
Reactor Scram on HL pressure			0.24 ± 0.01
Primary coolant pumps tripped			0.94 ± 0.01
Pressurizer emptied			15.4 ± 1.0
Accumulator injection initiated			16.8 ± 0.1
High-pressure injection initiated			23.90 ± 0.02
PCT reached			28.47 ± 0.02
Low-pressure injection initiated			37.32 ± 0.02
Accumulator empty			49.6 ± 0.1
Core quench complete			65 ± 2
Experiment terminated		]	107.1

4 [ ]

Table 3-11
Comparison of S-RELAP5 and LOFT LP-02-6 Steady-State Conditions

Parameter	S-RELAP5	Test LP-02-6 (Reference 12, Table 3)
Core Power (MWt)		46.0 ± 1.2
Hot Leg Pressure (Intact) (MPa)		15.09 ± 0.08
Hot Leg Temperature (Intact) (K)		589.0 ± 1.8[5]
Cold Leg Temperature (Intact) (K)		555.9 ± 1.1
Mass Flow Rate (kg/s)		248.7 ± 2.6
Pressurizer Level (m)		1.04 ± 0.04
Steam Generator Secondary Pressure (MPa)		not specified
Steam Generator Secondary Level (m)		not specified
Steam Flow Rate (kg/s)		not specified
Feedwater Flow Rate (kg/s)		not specified
Feedwater Temperature (K)		not specified

[5] Cold leg temperature (555.9 K) + core ΔT (33.1 K). Error based on RMS of uncertainties.

Table 3-12
Event Setpoints and Boundary Conditions for Simulation of LOFT Test LP-02-6

Parameter	Value (Reference 1, Table 8.3-9)
Test Initiation (s)	0.00
Reactor Scram Signal (Hot Leg Pressure) (MPa)	14.80
Reactor Scram Signal (time) (s)	1.28
HPIS Initiation (s)	24.77
LPIS Initiation (s)	37.32
Accumulator Nitrogen Volume (m^3)	0.84
Effective Accumulator Liquid Volume (m^3)	1.32
Accumulator Liquid Level (m)	2.10
Accumulator Standpipe Position (m)	1.12
Accumulator Pressure (MPa)	4.11
Accumulator Temperature (K)	302.0

Table 3-13
Event Sequence for LOFT Test LP-02-6

Event	Time (sec)		
	S-RELAP5[6]		Measured Data
	GALILEO	COPERNIC	(Reference 12, Table 5)
Break initiated			0.0
Reactor Scram on HL pressure			0.1 ± 0.01
Primary coolant pumps tripped			0.8 ± 0.01
Blowdown PCT reached			4.9 ± 0.2
Pressurizer emptied			15.5 ± 0.5
Accumulator injection initiated			17.5 ± 0.5
Lower plenum refill complete			30.7 ± 0.2
Low-pressure injection initiated			34.8 ± 0.01
Refill/Reflood PCT reached			41.0 ± 0.2
Accumulator injection complete			57 ± 5
Core quench complete			56 ± 0.2

6 [ ]

Table 3-14
Comparison of S-RELAP5 and LOFT LP-LB-1 Steady-State Conditions

Parameter	S-RELAP5	Test LP-LB-1 (Reference 13, Table 2)
Core Power (MWt)		49.3 ± 1.2
Hot Leg Pressure (Intact) (MPa)		14.90 ± 0.08
Hot Leg Temperature (Intact) (K)		585.8 ± 1.7[7]
Cold Leg Temperature (Intact) (K)		556 ± 1
Mass Flow Rate (kg/s)		305.8 ± 2.6
Pressurizer Level (m)		1.04 ± 0.04
Steam Generator Secondary Pressure (MPa)		not specified
Steam Generator Secondary Level (m)		not specified
Steam Flow Rate (kg/s)		not specified
Feedwater Flow Rate (kg/s)		not specified
Feedwater Temperature (K)		not specified

[7] Cold leg temperature (556 K) + core ΔT (29.8 K). Error based on RMS of uncertainties.

Table 3-15
Event Setpoints and Boundary Conditions for Simulation of LOFT Test LP-LB-1

Parameter	Value (Reference 1, Table 8.3-12)
Test Initiation (s)	0.00
Reactor Scram Signal (Hot Leg Pressure) (MPa)	14.50
Reactor Scram Signal (time) (s)	0.008
Primary Coolant Pump Trip (s)	1.2
HPIS Initiation (s)	N/A
LPIS Initiation (s)	31.0
Accumulator Nitrogen Volume (m^3)	0.66
Effective Accumulator Liquid Volume (m^3)	0.72
Accumulator Liquid Level (m)	2.36
Accumulator Standpipe Position (m)	1.74
Accumulator Pressure (MPa)	4.20
Accumulator Temperature (K)	305.0

Table 3-16
Event Sequence for LOFT Test LP-LB-1

Event	Time (sec)		
	S-RELAP5[8]		Measured Data (Reference 13, Table 4)
	GALILEO	COPERNIC	
Break initiated	[		0.0
Reactor Scram on HL pressure			0.13 ± 0.01
Primary coolant pumps tripped			0.24 ± 0.01
Blowdown PCT reached			12.9 ± 0.5
Pressurizer emptied			15 ± 1
Accumulator injection initiated			17.5 ± 0.05
Refill/Reflood PCT reached			26.8 ± 0.5
Low-pressure injection initiated			32 ± 1
Lower plenum refill complete			34.5 ± 0.5
Accumulator empty			40 ± 1
Accumulator injection complete			46 ± 1
Core quench complete			72 ± 1
Experiment terminated		]	132

8 [ ]

Table 3-17: Expanded Model Parameter Uncertainty Ranges

[ ]

Table 3-18: Expanded Phenomenological Model Parameters

[ ]

9 [ ]

Table 3-19
Technical Changes from the Approved RLBLOCA EM Included in the Sample Problem

[

]

Table 3-20
3-Loop Westinghouse - Plant Parameter Values and Ranges

Table 3-20
3-Loop Westinghouse - Plant Parameter Values and Ranges
(Continued)

[ ]

Table 3-20
3-Loop Westinghouse - Plant Parameter Values and Ranges
(Continued)

[ ]

Table 3-21
3-Loop Westinghouse - Statistical Distributions Used for Process Parameters

[ ]

Table 3-22
Summary of Major Parameters for the Demonstration Case

[ ]

Table 3-23
Comparison of Results for the Demonstration Case

[ ]

Table 3-24
Comparison of Rupture Results for the Demonstration Case

[ ]

Figure 3-1

[

]

[

]

Figure 3-2

[ ]

[ ]

Figure 3-3

[

]

[

]

Figure 3-4
Schematic View of the LOFT Test Facility

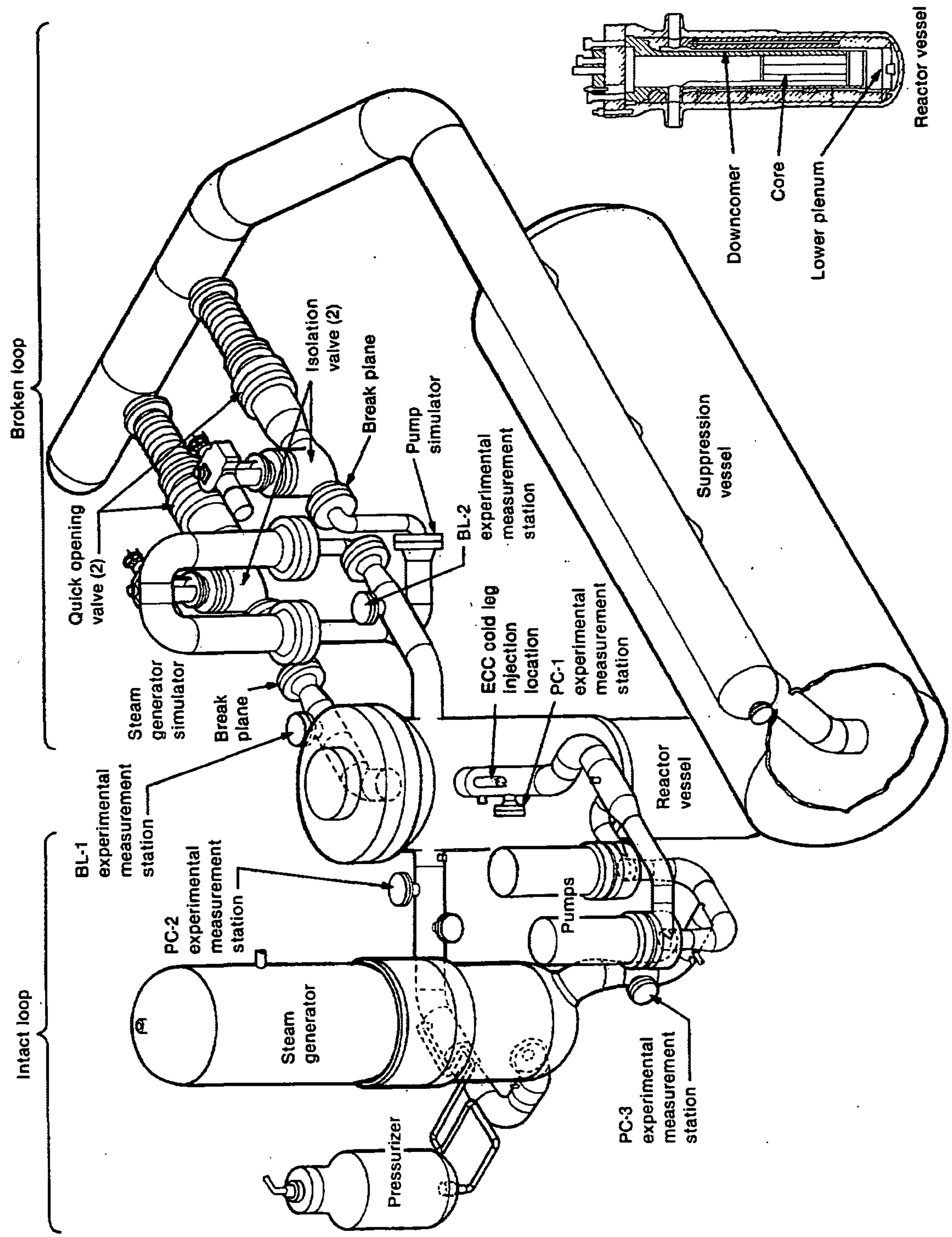

Figure 3-5
LOFT Large Break Model Nodalization

Figure 3-6
S-RELAP5 Model of LOFT Downcomer and Core Region

[ ]

Figure 3-7
LOFT Test L2-3 Reactor Vessel Upper Plenum Pressure

Figure 3-8
LOFT Test L2-3 Pressurizer Collapsed Liquid Level

Figure 3-9
LOFT Test L2-3 BLCL Average Volume Fluid Density

[ ]

Figure 3-10
LOFT Test L2-3 BLCL Mass Flow Rate

[ ]

Figure 3-11
LOFT Test L2-3 Reactor Vessel Upper Plenum Fluid Temperature

[ ]

Figure 3-12
LOFT Test L2-3 Accumulator Liquid Level

[ ]

Figure 3-13
LOFT Test L2-3 Mass Flow Rate from LPIS

[ ]

Figure 3-14
LOFT Test L2-3 Central Fuel Assembly Instrumented Fuel Rod Locations and S-RELAP5 Axial Fuel Rod Temperature Calculation Locations

Figure 3-15
LOFT Test L2-3 Hot Rod Cladding Temperature at 26 Inches

[ ]

Figure 3-16
LOFT Test L2-3 Comparison of PCTs versus Core Elevations

[ ]

Figure 3-17
LOFT Test L2-5 Reactor Vessel Upper Plenum Pressure

[ ]

Figure 3-18
LOFT Test L2-5 Pressurizer Collapsed Liquid Level

[ ]

Figure 3-19
LOFT Test L2-5 BLCL Average Volume Fluid Density

[ ]

Figure 3-20
LOFT Test L2-5 BLCL Mass Flow Rate

[ ]

Figure 3-21
LOFT Test L2-5 Reactor Vessel Upper Plenum Fluid Temperature

Figure 3-22
LOFT Test L2-5 Accumulator Pressure

Figure 3-23
LOFT Test L2-5 Mass Flow Rate from LPIS

[ ]

Figure 3-24
LOFT Test L2-5 Central Fuel Assembly Instrumented Fuel Rod Locations and S-RELAP5 Axial Fuel Rod Temperature Calculation Locations

[ ]

Figure 3-25
LOFT Test L2-5 Hot Rod Cladding Temperature at 26 Inches

[ ]

Figure 3-26
LOFT Test L2-5 Fuel Centerline Temperature

[ ]

Figure 3-27
LOFT Test L2-5 Comparison of PCTs versus Core Elevations

Figure 3-28
LOFT Test LP-02-6 Reactor Vessel Upper Plenum Pressure

Figure 3-29
LOFT Test LP-02-6 Pressurizer Collapsed Liquid Level

Figure 3-30
LOFT Test LP-02-6 BLCL Average Volume Fluid Density

Figure 3-31
LOFT Test LP-02-6 BLCL Mass Flow Rate

Figure 3-32
LOFT Test LP-02-6 Reactor Vessel Upper Plenum Fluid Temperatures

Figure 3-33
LOFT Test LP-02-6 Accumulator Liquid Level

[ ]

Figure 3-34
LOFT Test LP-02-6 Mass Flow Rate from LPIS

[ ]

Figure 3-35
LOFT Test LP-02-6 Central Assembly Instrumented Fuel Rod Locations and S-RELAP5 Axial Fuel Rod Temperature Calculation Locations

[ ]

Figure 3-36
LOFT Test LP-02-6 Hot Rod Cladding Temperatures (Solid Pellet) at 26 Inches

[ ]

Figure 3-37
LOFT Test LP-02-6 Fuel Centerline Temperature at 27 Inches

[ ]

Figure 3-38
LOFT Test LP-02-6 Comparison of PCTs versus Core Elevations

[ ]

Figure 3-39
LOFT Test LP-LB-1 Reactor Vessel Upper Plenum Pressure

[ ]

Figure 3-40
LOFT Test LP-LB-1 Pressurizer Collapsed Liquid Level

Figure 3-41
LOFT Test LP-LB-1 BLCL Average Volume Fluid Density

Figure 3-42
LOFT Test LP-LB-1 BLCL Mass Flow Rate

Figure 3-43
LOFT Test LP-LB-1 Reactor Vessel Upper Plenum Fluid Temperatures

[ ]

Figure 3-44
LOFT Test LP-LB-1 Accumulator Liquid Level

Figure 3-45
LOFT Test LP-LB-1 Mass Flow Rate from LPIS

Figure 3-46
LOFT Test LP-LB-1 Central Assembly Instrumented Fuel Rod Locations and S-RELAP5 Axial Fuel Rod Temperature Calculation Locations

Figure 3-47
LOFT Test LP-LB-1 Hot Rod Cladding Temperatures at 27 Inches

[ ]

Figure 3-48
LOFT Test LP-LB-1 Fuel Centerline Temperature

[ ]

Figure 3-49
LOFT Test LP-LB-1 Comparison of PCTs versus Core Elevations

[

]

Figure 3-50
Comparison of GALILEO and COPERNIC PCT Results

[ ]

Figure 3-51
Comparison of GALILEO and COPERNIC MLO

[ ]

Figure 3-52
Comparison of GALILEO and COPERNIC PCT Independent of Elevation for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-53
Comparison of GALILEO and COPERNIC Peak Node Surface Temperature for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-54
Comparison of GALILEO and COPERNIC Fuel Centerline Temperature for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-55
Comparison of GALILEO and COPERNIC Rod Pressure for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-56
Comparison of GALILEO and COPERNIC PCT Node Gap Width for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-57
Comparison of GALILEO and COPERNIC PCT Node Gap Conductance for Fresh UO_2 Rod – Case 018

[ ]

Figure 3-58
Comparison of GALILEO and COPERNIC PCT Independent of Elevation for Burned UO_2 Rod – Case 046

[ ]

Figure 3-59
Comparison of GALILEO and COPERNIC Peak Node Surface Temperature for Burned UO_2 Rod – Case 046

[ ]

Figure 3-60
Comparison of GALILEO and COPERNIC Fuel Centerline Temperature for Burned UO_2 Rod – Case 046

[ ]

Figure 3-61
Comparison of GALILEO and COPERNIC Rod Pressure for Burned UO_2 Rod – Case 046

[ ]

Figure 3-62
Comparison of GALILEO and COPERNIC PCT Independent of Elevation for Fresh 2% Gad Rod – Case 021

Figure 3-63
Comparison of GALILEO and COPERNIC Peak Node Surface Temperature for Fresh 2% Gad Rod – Case 021

Figure 3-64
Comparison of GALILEO and COPERNIC Fuel Centerline Temperature for Fresh 2% Gad Rod – Case 021

Figure 3-65
Comparison of GALILEO and COPERNIC Rod Pressure for Fresh 2% Gad Rod – Case 021

Figure 3-66
Comparison of GALILEO and COPERNIC PCT Independent of Elevation for Burned 8% Gad Rod – Case 012

Figure 3-67
Comparison of GALILEO and COPERNIC Peak Node Surface Temperature for Burned 8% Gad Rod – Case 012

Figure 3-68
Comparison of GALILEO and COPERNIC Fuel Centerline Temperature for Burned 8% Gad Rod – Case 012

[ ]

Figure 3-69
Comparison of GALILEO and COPERNIC Rod Pressure for Burned 8% Gad Rod – Case 012

[ ]

4.0 GALILEO IMPLEMENTATION IN THE SBLOCA EM

4.1 *Regulatory Requirements Summary*

10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," paragraph (a)(1)(i) requires that light-water nuclear reactors fueled with uranium oxide pellets within cylindrical Zircaloy or ZIRLO cladding must be provided with an emergency core cooling system (ECCS) that must be designed so that its calculated cooling performance following postulated loss-of-coolant accidents (LOCA) conforms to the criteria set forth in paragraph 50.46(b). Paragraph (a)(1)(ii) of 10 CFR 50.46 states that an ECCS evaluation model may be developed in conformance with the required and acceptable features of appendix K ECCS Evaluation Models. The approved SBLOCA EM in References 3 and 4 conforms with the requirements of ECCS analysis set forth in Appendix K to 10 CFR 50.

The ECCS cooling performance criteria outlined in 10 CFR 50.46(b) are as follows:

1. Peak cladding temperature. The calculated maximum fuel element cladding temperature shall not exceed 2200°F.
2. Maximum cladding oxidation. The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.
3. Maximum hydrogen generation. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.
4. Coolable geometry. Calculated changes in core geometry shall be such that the core remains amenable to cooling.

5. Long-term cooling. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

4.2 *Scenario Identification*

The scenario identification, including event description, limiting break conditions, as well as the figures of merit are described for the approved SBLOCA EM in Section 3.0 of Reference 3. The supplemented SBLOCA EM is applicable to the same transient scenario, PWR models and retains the same figures of merit as the approved EM.

4.3 *Evaluation Model Requirements*

The EM requirements for the approved SBLOCA EM are described in Section 3.1 of Reference 3 which specifies that the approved SBLOCA EM complies with the requirements of the regulations for ECCS given in 10 CFR Part 50, §50.46 and Appendix K to 10 CFR Part 50.

4.4 *Assessment Data Base Summary*

4.4.1 EM Changes Roadmap and Objectives for Assessment Data Base

[ ]

The discussion above focuses the validation objectives on the EM features that are directly affected by the FPC change. This leads to one major objective for the assessment base which is:

[ ]

4.4.2 Assessment Data Base

The approved SBLOCA EM does not provide a centralized assessment matrix, however, multiple assessments are provided in References 3 and 4. In assessing the validation needs identified above, the change in fuel models and the overall code performance can be determined using IETs. Given that LOFT is the only test facility with a nuclear fuel core, the selection for this assessment is the set of LOFT tests used in the approved SBLOCA EM (Reference 4, Response to RAI 3). Taking into account these considerations, the experimental database to be used for the supplemented EM is provided in Table 4-1.

4.5 *Evaluation Model Description*

Since the EM changes concern the FPC models used in S-RELAP5, the discussion in the following paragraphs is focused on the aspects related to these models and their implementation. [

]

[

]

4.6 *Assessment Results*

4.6.1 LOFT Small Break Tests L3-6 and L8-1

In order to justify the applicability of the computer code S-RELAP5 physical models and modeling techniques to SBLOCAs with the reactor coolant pumps running, Framatome benchmarked the S-RELAP5 code against the LOFT L3-6 test as part of RAI-3 in Reference 4. This test simulates a 2.5% small break (4 inch equivalent) in the cold leg of a large Pressurized Water Reactor (PWR). During the test, the accumulators and Low Pressure Injection System (LPIS) were not activated. Safety injection water was provided by means of the High Pressure Injection System (HPIS), which was injected into the downcomer. The primary coolant pumps were not tripped until the end of the test.

In order to capture the transition from a two-phase mixture to vapor in the downcomer and the communication between the downcomer and lower plenum, Framatome proposed to use LOFT L8-1 test for the S-RELAP5 code benchmark as part of RAI-3 in Reference 4. The LOFT L8-1 test is an extension of test L3-6 and it was designed to investigate the core response following core uncovery. The objective of the test was to allow the reactor vessel liquid level to drop below the top of the core and produce fuel rod heat-up. This was accomplished by terminating safety injection and tripping the pumps at the end of test L3-6.

The simulation of the L3-6 test showed adequate core cooling by forced convection of a two-phase mixture during the pump running period. As the transient progressed, the void fraction in the reactor coolant system (RCS) increased steadily, reaching a stage when only highly voided fluid was pumped around the system with liquid being present in the RCS lower regions or collecting in pockets at higher elevations. During this period, the code captured correctly the fluid transition from a two-phase mixture to single-phase vapor in the downcomer region as well as the communication between the downcomer and the lower plenum. This is demonstrated by very good predictions of system mass inventory, coolant temperatures, primary system pressure, and fluid densities. Further, as the pumps tripped during the simulation of the L8-1 test, the S-RELAP5 code accurately predicted the core two-phase mixture collapse and core uncovery, followed by fuel cladding temperature rise and peak cladding temperature.

4.6.1.1 S-RELAP5 SBLOCA Model of LOFT Facility

The S-RELAP5 model of the LOFT facility is presented in Figure 4-1 and Figure 4-2. The methodology utilized for the S-RELAP5 benchmark analysis follows as closely as practicable the guidelines documented in References 3 and 4, with the exception of GALILEO being used as the fuel performance code in the updated analysis.

Key features of the benchmark model include the following:

Table 4-2 compares the S-RELAP5 calculated initial conditions using either GALILEO or RODEX2 as the fuel performance code with the conditions reached during the experiment. A time sequence of the important events during Tests L3-6/L8-1 is presented in Table 4-3. Figure 4-3 through Figure 4-14 present several calculated results and comparisons of measured parameters with results of S-RELAP5 using either GALILEO or RODEX2 as the fuel performance code.

4.6.1.2 S-RELAP5 Code Prediction vs. LOFT L3-6 Test

The S-RELAP5 simulations of the L3-6 test were started from nearly identical initial conditions as those established in the experiment (Table 4-2). Table 4-3 presents a sequence of events resulting from test runs. The transients were initiated 5.8 seconds after reactor scram. The Primary Coolant Pumps (PCPs) continued to operate at constant speed until they were tripped at 2371.4 seconds in both the run with GALILEO and the run with RODEX2, when the intact loop pressure reached approximately 2.3 MPa. This was followed by the termination of HPIS, which marked the end of the L3-6 test simulation and the beginning of the L8-1 experiment.

Figure 4-3 compares the calculated and measured pressures in the intact loop cold leg.

[

]

[ ]

4.6.1.3 S-RELAP5 Code Prediction vs. LOFT L8-1 Test

The RCPs were tripped at 2371.4 seconds, marking the end of the L3-6 test and the beginning of the L8-1 test. The reactor vessel liquid mixture subsequently collapsed to the lower core elevations, exposing the high power core regions to a steam environment. The fuel rod temperature excursion began at the higher elevations (Figure 4-13). The S-RELAP5 code using GALILEO predicted a Peak Cladding Temperature (PCT) [

]

The accumulator and HPIS A and B systems were initiated after the break was isolated at 2460.4 seconds. The flow of subcooled emergency core cooling system water flooded the downcomer and the lower plenum regions, as captured in Figure 4-12. Subsequently, the core was quenched within seconds (Figure 4-13) and the accumulator flow was terminated marking the end of the L8-1 test.

4.6.1.4 Conclusions

It is concluded that S-RELAP5 can properly capture the phenomena experienced during the LOFT L3-6 and L8-1 test sequence. The use of GALILEO as the fuel performance code gives results [

]

4.7 *Evaluation Model Implementation*

4.7.1 Evaluation Model Implementation Changes

This section provides the limited changes identified in the EM implementation for the application of GALILEO in the SBLOCA EM. The technical upgrades identified in Table 4-5 are an integral part of the supplemented SBLOCA EM. Other than the changes identified herein, all the other features of the SBLOCA EM remain intact as currently implemented in the approved EM.

4.7.1.1 [ ]

The approved SBLOCA EM (Reference 3) stated that the peak cladding temperature

[

]

[

]

4.7.1.2 [ ]

[

]

All of the other features of the approved SBLOCA EM remain unchanged.

4.7.1.3 Guidelines for GALILEO Input for SBLOCA

This section provides guidance for developing GALILEO input for use in SBLOCA analyses. [

]

The key input parameters which should be verified, in addition to the fuel design data, are shown in Table 4-4. [

]

4.7.2 SBLOCA Sample Problem with GALILEO

4.7.2.1 Introduction

This section provides a sample problem SBLOCA analysis for a CE 2x4-loop PWR. This sample problem analysis is presented to provide a comparative evaluation of a representative solution to the SBLOCA evaluation using the approved EM (References 3 and 4) with RODEX2 and the supplemented EM using GALILEO (Reference 7). The sample problem is not fully representative of any specific plant. The analysis model simulates representative core operating power and peaking factors similar or higher than found in the current operating fleet. The application has been reviewed to assure that it offers an accurate representation of the S-RELAP5 based SBLOCA evaluation model (References 3 and 4) findings and conclusions.

The sample problem uses Framatome fuel with $M5_{Framatome}$ cladding and utilizes the GALILEO code for fuel calculations within S-RELAP5. Additional RODEX2 and GALILEO rods were added to the model for direct comparison. Discussion of the results shown in the following sections is focused on the comparison of results between GALILEO and RODEX2 fuel rod thermal response to the same system transient.

4.7.2.2 Description of the Sample Problem

This sample SBLOCA analysis was performed in accordance with the NRC-approved methodology described in References 3 and 4.

The plant is a CE 2x4-loop design with a rated thermal power of 2754 MWt (including measurement uncertainty). The loops contain four RCPs, two U-tube steam generators and a pressurizer. [

]

The analysis is focused on the comparison of the results obtained with RODEX2, the current FPC used in the approved EM, and its alternative, GALILEO.

4.7.2.2.1 Description of Analytical Models

The present Topical Report adds GALILEO (Reference 7) functionality to the SBLOCA EM. GALILEO has the same capabilities as RODEX2, namely computation of the initial fuel stored energy, fission gas release, and the transient fuel-cladding gap conductance. This analysis was performed using S-RELAP5, GALILEO and RODEX2.

[ ]

[ ]

The following differences from the approved EM in References 3 and 4 which were included in this analysis are summarized in Table 4-5. The technical upgrades identified in Table 4-5 are an integral part of the supplemented SBLOCA EM. Other than the differences described in Table 4-5, the calculations follow all the requirements of the approved SBLOCA EM described in References 3 and 4.

[ ]

[

]

4.7.2.3 Comparison of SBLOCA Results Using RODEX2 and GALILEO

A spectrum of cold leg break sizes [

]

A comparison of the results for the GALILEO hot rod and the corresponding RODEX2 hot rod for the limiting break size is provided in Table 4-8. Table 4-9 and Table 4-10 provide comparisons of the results for the entire spectrum of break sizes analyzed.

A general illustration of the results from the entire spectrum of breaks is provided in Figure 4-15, [

]

Similar results are obtained for the MLO, as illustrated in Figure 4-16, [

]

The following figures compare several parameters calculated by GALILEO and RODEX2 for the [

]

Additional figures comparing several parameters calculated by GALILEO and RODEX2 are also considered for [

]

[

]

4.7.2.4 Conclusions

[ ]

Table 4-1
Assessment Matrix Tests and Phenomena Addressed in the Supplemented SBLOCA EM

[ ]

Table 4-2
Initial Conditions for Test LOFT L3-6

Parameter	**S-RELAP5 (GALILEO)**	**S-RELAP5 (RODEX2)**	**Test L3-6/L8-1 (Ref. 16, p.3)**
Core Power (MWt)			50 ± 1
Hot Leg Pressure (Intact) (MPa)			14.87 ± 0.14
Hot Leg Temperature (Intact) (K)			577.1 ± 1.8
Cold Leg Temperature (Intact) (K)			557.9 ± 1.1
Mass Flow Rate (kg/s)			483.3 ± 2.6
Pressurizer Level (m)			1.18 ± 0.11
Steam Generator Secondary Pressure (MPa)			5.57 ± 0.06
Steam Generator Secondary Level[14] (m)			0.22 ± 0.03
Steam Flow Rate (kg/s)			27.8 ± 0.1

[14] Measured from 2.95m above the top of tube sheet: 2.95 + 0.22 = 3.17 m – Ref.17, pg.5

Table 4-3
Sequence of Events for Tests LOFT L3-6/L8-1

Event	Time (sec)		
	S-RELAP5[15]		Measured Data (Ref. 18, p. 65)
	(GALILEO)	(RODEX2)	
Reactor Scram			-5.8 ± 0.2
Break initiated			0.0
Intact loop cold leg voiding begins			31.4 ± 5.0
Primary coolant pumps tripped			2371.4 ± 0.2
Cladding temperature excursion begins at PCT node			2394.6 ± 0.2
HPIS A for L3-6 terminated			2428.2 ± 0.2
Break isolated			2460.4 ± 0.2
Accumulator initiated			2462.2 ± 0.2
HPIS A + B initiated[16]			2463.8 ± 0.2
Max cladding temperature			2465.8 ± 0.2
Accumulator isolated			2506.6 ± 0.2

[15] The break opening is defined at 0.0 sec in the test, with reactor scram occurring 5.8 seconds earlier. [ ]

[16] HPIS A starts at 2463.6 sec and HPIS B starts at 2463.8 sec in the test. Used the later of the two times and assumed the pumps started concurrently.

Table 4-4
GALILEO Key Input Parameters for SBLOCA

[ ]

Table 4-5
Technical Changes from the Approved SBLOCA EM Included in the Sample Problem

Table 4-6
SBLOCA Sample Problem Design Inputs

[ ]

17 [ ]

Table 4-7
Comparison of FPC Initialization Parameters at LOCA Initiation Conditions

[

]

Table 4-8
Comparison of Results for the Limiting Break Size

[ ]

Table 4-9

Break Spectrum Results for the GALILEO [ ] Hot Rod

[ ]

Table 4-10

Break Spectrum Results for the RODEX2 [ ] Hot Rod

[ ]

Figure 4-1
S-RELAP5 Nodalization Diagram for LOFT L3-6/L8-1 Test

[ ]

Figure 4-2
S-RELAP5 Model of LOFT L3-6/L8-1 Downcomer and Core Regions

[ ]

Figure 4-3
Comparison of Cold Leg Pressure for the L3-6 Test

Figure 4-4
Comparison of Break Mass Flow Rate for the L3-6 Test

Figure 4-5
Comparison of Primary System Mass Inventory for the L3-6 and L8-1 Tests

[ ]

Figure 4-6
Comparison of Downcomer Pressure for the L3-6 Test

[ ]

Figure 4-7
Comparison of Downcomer Temperature for the L3-6 Test

Figure 4-8
Comparison of Lower Plenum Temperature for the L3-6 Test

Figure 4-9
Comparison of the Intact Loop Density for the L3-6 Test

Figure 4-10
Comparison of Hot Rod Cladding Temperature for the L3-6 Test

Figure 4-11
Comparison of Hot Rod Centerline Temperature for the L3-6 Test

Figure 4-12
Comparison of Fluid Temperature at Vessel Bottom for L8-1 Test

Figure 4-13
Comparison of Hot Rod Cladding Temperature for the L8-1 Test

[ ]

Figure 4-14
Comparison of Hot Rod Centerline Temperature for the L8-1 Test

[ ]

Figure 4-15
Comparison of GALILEO and RODEX2 PCT Results

Figure 4-16
Comparison of GALILEO and RODEX2 MLO Results

Figure 4-17
Comparison of GALILEO and RODEX2 PCT Independent of Elevation –
[ ]

[

]

Figure 4-18
Comparison of GALILEO and RODEX2 PCT Node Surface Temperature – [ ]

[ ]

Figure 4-19
Comparison of GALILEO and RODEX2 Fuel Centerline Temperature –
[ ]

[

]

Figure 4-20
Comparison of GALILEO and RODEX2 Rod Pressure –
[ ]

[ ]

Figure 4-21
Comparison of GALILEO and RODEX2 PCT Node Gap Width –
[ ]

[ ]

Figure 4-22
Comparison of GALILEO and RODEX2 PCT Node Gap Conductance –
[ ]

[ ]

Figure 4-23
Comparison of GALILEO and RODEX2 PCT Independent of Elevation –
[ ]

[

]

Figure 4-24
Comparison of GALILEO PCT Node and Consistent RODEX2 Node Surface Temperature – [ ]

[ ]

Figure 4-25
Comparison of GALILEO and RODEX2 Fuel Centerline Temperature –
[ ]

[

]

Figure 4-26
Comparison of GALILEO and RODEX2 Rod Pressure –
[ ]

[

]

Figure 4-27
Comparison of GALILEO PCT Node and Consistent RODEX2 Node Gap Width – [ ]

[

]

Figure 4-28
Comparison of GALILEO PCT Node and Consistent RODEX2 Node
Gap Conductance – [ ]

[

]

5.0 REFERENCES

1. EMF-2103(P)(A), Revision 3, Realistic Large Break LOCA Methodology for Pressurized Water Reactors, AREVA, June 2016.
2. EMF-2103(P)(A), Revision 0, Realistic Large Break LOCA Methodology for Pressurized Water Reactors, AREVA, April 2003.
3. EMF-2328(P)(A), Revision 0, PWR Small Break LOCA Evaluation Model, S-RELAP5 Based, Framatome ANP, March 2001.
4. EMF-2328(P)(A), Revision 0, Supplement 1(P)(A), Revision 0, PWR Small Break LOCA Evaluation Model, S-RELAP5 Based, AREVA, December 2016.
5. NUREG/CR-5249, Revision 4, Quantifying Reactor Safety Margins, INEL, December 1989.
6. Regulatory Guide 1.157, Best-Estimate Calculations of Emergency Core Cooling System Performance, US NRC, May 1989.
7. ANP-10323P Revision 1, GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors, Framatome, June 2018.
8. FS1-0004682, Revision 7, GALILEO Fuel Rod Performance Code Theory Manual, Framatome, July 2020.
9. BAW-10231P-A, Revision 1, COPERNIC Fuel Rod Design Computer Code, Framatome ANP, January 2004.
10. QLR-L2-3, Quick Look Report on LOFT Nuclear Experiment L2-3, EG&G Idaho, 1979.
11. NUREG/CR-2826/EGG-2210, Experiment Data Report for LOFT Large Break Loss-of-Coolant Experiment L2-5, EG&G Idaho, 1982.
12. OECD LOFT-T-3404, Quick-Look Report on OECD LOFT Experiment LP-02-6, EG&G Idaho, 1983.

13. OECD LOFT-T-3504, Quick-Look Report on OECD LOFT Experiment LP-LB-1, EG&G Idaho, 1984.

14. BAW-10227P Revision 2, Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel, Framatome, December 2019.

15. NUREG-0800, Standard Review Plan, Section 15.6.5 Loss-Of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary, Revision 3, US NRC, March 2007.

16. EGG-LOFT-5318, Quick-Look Report on LOFT Nuclear Experiment L3-6/L8-1, EG&G Idaho, December 1980.

17. EGG-LOFT-5480, Four-Inch Equivalent Break Loss-of-Coolant Experiments: Posttest Analysis of LOFT Experiments L3-1, L3-5, (pumps off), and L3-6 (pumps on), EG&G Idaho, October 1981.

18. EGG-LOFT-5471, Experiment Results Report for LOFT Nuclear Experiments L3-5, L3-6, and L8-1, EG&G Idaho, July 1981.

19. FS1-0004683, Revision 4, GALILEO Fuel Rod Performance Code Verification and Validation Report, Framatome, April 2018.

20. XN-NF-81-58PA, Revision 2, Supplements 1 and 2, RODEX2 Fuel Rod Thermal-Mechanical Response Evaluation Model, Exxon Nuclear Company, 1984.

21. ANP-3640Q1P, Revision 0, Palo Verde Units 1, 2 and 3 Small Break LOCA Summary Report NRC RAI Responses, Framatome, September 2019.

22. ANP-3640Q2P, Revision 0, Palo Verde Units 1, 2 and 3 Small Break LOCA Summary Report NRC RAI Responses, Framatome, November 2019.

23. ANP-3640P, Revision 0, Palo Verde Units 1, 2, and 3 Small Break LOCA Summary Report, Framatome, March 2018.

24. BAW-10240(P)-A, Revision 0, Incorporation of M5 Properties in Framatome ANP Approved Methods, Framatome ANP, September 2002.

Correspondence for
ANP-10349NP-A, Revision 0

framatome

October 7, 2020
NRC:20:023

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

Request for Review and Approval of ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods"

Framatome Inc. (Framatome) requests the NRC's review and approval of the topical report ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods" for referencing in licensing actions. The topical report ANP-10349P describes the implementation of the fuel performance code GALILEO into Framatome PWR LOCA methods.

Framatome would appreciate NRC approval of this topical report by October 2021.

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.

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

If you have any questions related to this submittal please contact Ms. Gayle F. Elliott, (Deputy Director, Licensing & Regulatory Affairs). She may be reached by telephone at 434-832-3347 or by e-mail at Gayle.Elliott@framatome.com.

Sincerely,

Gary Peters

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: N. Otto
Project 728

Enclosures:

1 ANP-10349P Revision 0 (PROPRIETARY)
2 ANP-10349NP Revision 0 (NON-PROPRIETARY)
3 Notarized Affidavit

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

www.framatome.com

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

March 23, 2021

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

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING FRAMATOME TOPICAL REPORT, ANP-10349P, REVISION 0, "GALILEO IMPLEMENTATION IN LOCA METHODS" (EPID L-2020-TOP-0059)

Dear Mr. Peters:

By letter dated October 7, 2020 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20290A661), Framatome, Inc. (Framatome) submitted Topical Report (TR) ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods," to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. The NRC staff has reviewed the proposed TR and determined that additional information is needed to complete the review. Enclosed is the NRC staff's request for additional information (RAI) questions.

If you have any questions, please contact me at 301-415-6695 or by e-mail to Ngola.Otto@nrc.gov.

Sincerely,

Ngola A. Otto
Digitally signed by Ngola A. Otto
Date: 2021.03.23 11:14:29 -04'00'

Ngola Otto, Project Manager
Licensing Projects Branch
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 99902041
Project No. 728

Enclosure:
RAI Questions (Proprietary)

NOTICE: Enclosure transmitted herewith contains proprietary information. When separated from Enclosure, this transmittal document is decontrolled.

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING FRAMATOME TOPICAL REPORT, ANP-10349P, REVISION 0, "GALILEO IMPLEMENTATION IN LOCA METHODS" (EPID L-2020-TOP-0059) DATED MARCH 23, 2021

DISTRIBUTION:

PUBLIC
RidsNrrDorlLlpb
RidsNrrLADHarrison
RidsACRS_MailCTR
RidsNrrDss
RLukes, NRR
RidsNrrDorl
RidsResOd
DMorey, NRR
MPanicker, NRR
NOtto, NRR

ADAMS Accession Nos.:
ML21070A309 (Package)
ML21070A312 (Letter)
ML21070A314 (RAI Questions - Proprietary)

OFFICE	NRR/DORL/LLPB/PM	NRR/DORL/LLPB/LA	NRR/DSS/SNPB/BC
NAME	NOtto	DHarrison	RLukes
DATE	3/11/2021	3/12/2021	3/22/2021
OFFICE	NRR/DORL/LLPB/BC	NRR/DORL/LLPB/PM	
NAME	DMorey	NOtto	
DATE	3/22/2021	3/23/2021	

OFFICIAL RECORD COPY

U.S. NUCLEAR REGULATORY COMMISSION

REQUESTS FOR ADDITIONAL INFORMATION (RAIs)

FRAMATOME, INC. TOPICAL REPORT ANP-10349P

"GALILEO IMPLEMENTATION IN LOCA METHODS"

PROJECT NO. 728

DOCKET NO. 99902041

EPID: L-2020-TOP-0059

1.0 INTRODUCTION

By letter dated October 7, 2020 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML20290A661), Framatome, Inc. (Framatome) submitted Topical Report (TR) ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods," to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. Framatome stated in part that TR ANP-10349P, Revision 0, describes the implementation of the fuel performance code GALILEO into Framatome Pressurized Water Reactor (PWR) Loss of Coolant Accident (LOCA) methods.

Framatome currently has NRC approved TRs for small-break and large-break loss-of-coolant accident (LOCA) methodologies for Westinghouse (W) 3- and 4-loop designs and Combustion Engineering (CE) 2x4 designed Pressurized Water Reactors (PWR). Currently, the LOCA evaluation models for Westinghouse (W) and CE designed PWRs use S-RELAP5 as system thermal hydraulics code, that uses input from fuel performance code (FPC) such as COPERNIC for Realistic Large Break LOCA (RBLOCA) or RODEX2 for small break LOCA (SBLOCA). In ANP-10349P, Framatome seeks NRC staff approval to implement the approved GALILEO FPC in S-RELAP5 in the SBLOCA and RLBLOCA methodologies for W and CE design PWRs with recirculation (U-tube) steam generators, fuel assembly lengths of 14 feet or less, and Emergency Core Cooling Systems (ECCS) injection to the cold legs.

In order to confirm the analyses and references supporting the requested TR review, the NRC staff performed a virtual audit on February 10-11, 2021 (ADAMS Package Accession No. ML21035A067) of the documents related to fuel and cladding areas specific to implementation of GALILEO code and methodology in Framatome's LOCA analyses. The NRC staff requests for additional information from the review of ANP-10349P are provided below.

2.0 REGULATORY BASIS

10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors," paragraph (a)(1)(i) requires that LWRs with Uranium Dioxide (UO_2) fuel within Zircaloy or ZIRLO cladding must be provided with an emergency core cooling system (ECCS). ECCS must be designed so that its calculated cooling performance following postulated loss-of-coolant accidents (LOCA) conforms to the criteria set forth in paragraph 50.46(b).

3.0 REQUESTS FOR ADDITIONAL INFORMATION

1. Section 2, "GALILEO Implementation in S-RELAP5," of ANP-10349P summarizes implementation of GALILEO in S-RELAP5 thermal hydraulic system code for performing LOCA analyses. Section 2, states in part that [ ]

   (a) Provide details of the [ ] The details must include fuel performance code (FPC) parameters involved in the iterative process for convergence.

   (b) Provide examples to show that [ ] with GALILEO and S-RELAP5 [ ] with COPERNIC code and S-RELAP5.

2. Section 4.7.1, "Evaluation Model Implementation Changes," of ANP-10349P provide a short summary of how GALILEO code and methodology are implemented in SBLOCA analysis in combination with S-RELAP5 code. Also, the document [ ] describes in detail the guidelines for PWR SBLOCA analysis using S-RELAP5.

   (a) Provide details of GALILEO implementation in the SBLOCA evaluation model and related sensitivity analyses that are described in [ ] except the item [ ]

   (b) Discuss the differences in coupling between RODEX2 with S-RELAP5 and GALILEO with S-RELAP5 in an SBLOCA analysis.

3. Describe the deviation in process, if any, from RODEX2 implementation in SBLOCA analysis to GALILEO implementation in SBLOCA analysis.

4. Audit document, [ ]

   Provide details of analytical methodology, technical basis, thermo-mechanical response of fuel rod during normal plant operation and during SBLOCA, Summary of results and conclusion from the [ ]

framatome

April 23, 2021
NRC:21:014

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

Response to Request for Additional Information Regarding ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods"

Ref. 1: Letter, Gary Peters (Framatome Inc.) to Document Control Desk (NRC), "Request for Review and Approval of ANP-10349P, Revision 0, 'GALILEO Implementation in LOCA Methods'," NRC:20:023, October 7, 2020.

Ref. 2: Letter, Ngola Otto (NRC) to Gary Peters (Framatome Inc.), "Request for Additional Information Regarding Framatome Topical Report, ANP-10349P, Revision 0, 'GALILEO Implementation in LOCA Methods' (EPID L-2020-TOP-0059)," March 23, 2021.

Framatome Inc. (Framatome) requested the NRC's review and approval of the topical report ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods" in Reference 1. The NRC provided a Request for Additional Information (RAI) in Reference 2. A response to the RAI is enclosed with this letter.

Framatome considers some of the material contained in the enclosure to be proprietary. As required by 10 CFR 2.390(b), an affidavit is enclosed to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the RAI response are provided.

There are no commitments within this letter or its enclosures.

If you have any questions related to this information please contact Ms. Gayle F. Elliott, Deputy Director, Licensing & Regulatory Affairs, by telephone at (434) 832-3347, or by e-mail at Gayle.Elliott@framatome.com.

Sincerely,

Gary Peters

Gary Peters, Director
Licensing & Regulatory Affairs
Framatome Inc.

cc: N. Otto
Project 728

Attachments:

1. Proprietary copy of ANP-10349, Revision 0, Q1P, Revision 0
2. Non-proprietary copy of ANP-10349, Revision 0, Q1NP, Revision 0
3. Affidavit for withholding of proprietary information

framatome

Response to Request for Additional Information – ANP-10349P

ANP-10349Q1NP
Revision 0

Topical Report

April 2021

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
AFW	Auxiliary Feedwater
BOC	Beginning of Cycle
CWO	Core Wide Oxidation
EM	Evaluation Model
EOC	End of Cycle
EOL	End of Life
FPC	Fuel Performance Code
HHSI	High Head Safety Injection
LHGR	Linear Heat Generation Rate
LOCA	Loss of Coolant Accident
MLO	Maximum Local Oxidation
MOC	Middle of Cycle
MWR	Metal Water Reaction
PCT	Peak Cladding Temperature
RAI	Request for Additional Information
RCP	Reactor Coolant Pump
RLBLOCA	Realistic Large Break Loss of Coolant Accident
SBLOCA	Small Break Loss of Coolant Accident
SI	Safety Injection
W3	Westinghouse 3-Loop

INTRODUCTION

A request for additional information (RAI) related to the Topical Report ANP-10349P is documented in Reference 1. The response to this RAI is provided herein.

1.0 RAI-1

Question:

Section 2, "GALILEO Implementation in S-RELAP5," of ANP-10349P summarizes implementation of GALILEO in S-RELAP5 thermal hydraulic system code for performing LOCA analyses. Section 2, states in part that [

]

a. Provide details of the [ ] The details must include fuel performance code (FPC) parameters involved in the iterative process for convergence.

b. Provide examples to show that [ ] with GALILEO and S-RELAP5 [ ] with COPERNIC code and S-RELAP5.

Response:

Response to RAI.1.a:

A key to performing a LOCA analysis is the model used for calculating fuel rod performance. In particular, the initial operating temperature of the fuel pellets (stored energy), the internal fuel rod gas pressure, and the transient gap conductance are significant parameters which affect the calculated PCT. Framatome will use GALILEO to calculate the required fuel characteristics as a function of fuel rod exposure and power history for LOCA analysis as part of ANP-10349P.

The GALILEO fuel rod performance code was originally developed and NRC-approved for use by Framatome with respect to fuel rod mechanical design. The GALILEO code was incorporated in S-RELAP5 to permit coupled calculations of fuel rod thermal properties (thermal conductivity, heat capacity, and gap conductance) during both the steady-state and the transient phases of an S-RELAP5 LOCA analysis.

The fuel rod analysis for an S-RELAP5-based RLBLOCA/SBLOCA calculation proceeds in three steps:

[ ]

The data exchange between the GALILEO sub-code in S-RELAP5 and S-RELAP5 is presented in Figure 1-1.

[

]

Response to RAI.1.b:

As discussed in the response to RAI 1(a), [

]

[

]

For example, a case from the W3 sample problem was selected and analyzed further.

[

]

[ ]

Table 1-1 provides a summary of the information extracted [

]

The information presented in Table 1-1 indicates the [

]

Based on Table 1-1, the range of times to focus in are as follows:

- 0.0 to 2.0 seconds
- 2.0 to 4.0 seconds
- 4.0 to 6.0 seconds

- 8.0 to 10.0 seconds
- 13.7 to 13.9 seconds
- 20.6 to 20.8 seconds

Figure 1-2 through Figure 1-7 provides the fuel centerline temperature for [ ] for the time periods of interest at the PCT node [ ]

Figure 1-8 through Figure 1-13 provides the cladding temperature for [ ] for the time periods of interest at the PCT node [ ]

Figure 1-2 through Figure 1-13 shows [ ]

Figure 1-1
GALILEO/S-RELAP5 Data Exchange

[ ]

Figure 1-2
Centerline Temperature at PCT Node – [ ] – 0.0 to 2.0 Seconds

[

]

Figure 1-3
Centerline Temperature at PCT Node – [ ] – 2.0 to 4.0 Seconds

[

]

Figure 1-4

Centerline Temperature at PCT Node – [ ] – 4.0 to 6.0 Seconds

[ ]

Figure 1-5
Centerline Temperature at PCT Node – [ ] – 8.0 to 10.0 Seconds

[

]

Figure 1-6
Centerline Temperature at PCT Node – [ ] – 13.7 to 13.9 Seconds

[

]

Figure 1-7
Centerline Temperature at PCT Node – [ ] – 20.6 to 20.8 Seconds

[

]

Figure 1-8
Cladding Temperature at PCT Node – [ ] – 0.0 to 2.0 Seconds

[ ]

Figure 1-9
Cladding Temperature at PCT Node – [ ] – 2.0 to 4.0 Seconds

[ ]

Figure 1-10
Cladding Temperature at PCT Node – [ ] – 4.0 to 6.0 Seconds

[

]

Figure 1-11
Cladding Temperature at PCT Node – [ ] – 8.0 to 10.0 Seconds

[ ]

Figure 1-12
Cladding Temperature at PCT Node – [ ] – 13.7 to 13.9 Seconds

[

]

Figure 1-13
Cladding Temperature at PCT Node – [ ] – 20.6 to 20.8 Seconds

[ ]

Table 1-1 Summary of GALILEO [ ]

[ ]

2.0 RAI-2

Question:

Section 4.7.1, "Evaluation Model Implementation Changes," of ANP-10349P provide a short summary of how GALILEO code and methodology are implemented in SBLOCA analysis in combination with S-RELAP5 code. Also, the document [ ] describes in detail the guidelines for PWR SBLOCA analysis using S-RELAP5.

a. Provide details of GALILEO implementation in the SBLOCA evaluation model and related sensitivity analyses that are described in [ ] except the item [ ]

b. Discuss the differences in coupling between RODEX2 with S-RELAP5 and GALILEO with S-RELAP5 in an SBLOCA analysis.

Response:

Response to RAI.2.a:

The SBLOCA analysis consists of a series of break spectrum, delayed RCP trip, attached piped breaks, and sensitivity calculations. The calculation flow for an SBLOCA analysis is [ ]

[ ]

Response to RAI.2.b:

Both RODEX2 and GALILEO were integrated as sub-codes in S-RELAP5. The differences in the S-RELAP5 integration between RODEX2 and GALILEO consist primarily [ ]

[ ]

Table 2-1 GALILEO FPC [ ]

[ ]

3.0 RAI-3

Question:

Describe the deviation in process, if any, from RODEX2 implementation in SBLOCA analysis to GALILEO implementation in SBLOCA analysis.

Response:

The changes made to the SBLOCA analysis process for the implementation of GALILEO in the SBLOCA EM are limited to those described in Section 4.7.1 of the ANP-10349P-000 Topical Report (Reference 5).

4.0 RAI-4

Question:

Audit document, [

]

Provide details of analytical methodology, technical basis, thermo-mechanical response of fuel rod during normal plant operation and during SBLOCA, Summary of results and conclusion from the [ ]

Response:

As part of the implementation of the GALILEO fuel rode code, the study referenced in the RAI was performed in order to [

]

A detailed technical evaluation of the cladding thermal response during an SBLOCA transient was made. It was found that the cladding thermal response can potentially be affected by the following two important detrimental effects [

]

[ ]

Taking into account the conclusions from these sensitivity studies, the following recommendations for the implementation of GALILEO in the SBLOCA methodology were made:

[ ]

[ ]

5.0 REFERENCES

1. Letter from N. Otto (U.S. NRC) to Gary Peters (Framatome Inc.), "Request for Additional Information regarding Framatome Topical Report, ANP-10349P, Revision 0, "GALILEO Implementation in LOCA Methods" (EPID L-2020-TOP-0059)," dated March 23, 2021.

2. EMF-2103(P)(A) Revision 3, Realistic Large Break LOCA Methodology for Pressurized Water Reactors, June 2016.

3. EMF-2328(P)(A) Revision 0, PWR Small Break LOCA Evaluation Model, S-RELAP5 Based, March 2001.

4. EMF-2328(P)(A) Revision 0 Supplement 1(P)(A) Revision 0 PWR Small Break LOCA Evaluation Model, S-RELAP5 Based, December 2016.

5. ANP-10349P, Revision 0, GALILEO Implementation in LOCA Methods, October 2020.

Summary of Changes

There are no changes relative to ANP-10349NP, Revision 0