



**ACE/ATRIUM 11
BWR Critical Power
Correlation**

AREVA/NRC Meeting
Rockville, MD
May 12, 2015



**ACE/ATRIUM 11
BWR Critical Power
Correlation**

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Agenda

- ▶ **Objectives**
- ▶ **ACE Correlation History**
- ▶ **ACE/ATRIUM 11 – Audit KATHY Loop and Critical Power Testing**
- ▶ **ACE/ATRIUM 11 Critical Power Correlation, Report No. ANP-10335P**
- ▶ **Discussion of Status of U.S. NRC Review of the ACE/ATRIUM 11 Topical Report**
 - ◇ Topical report acceptance review
 - ◇ Schedule
- ▶ **Concluding Remarks**

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Schedule

- ▶ **Pre-submittal meeting – test program – Aug. 12, 2010**
- ▶ **Pre-submittal meeting – test axial power shapes – Nov. 16, 2010**
- ▶ **Audit testing/data collection – Jan. 29-Feb. 2, 2011**
- ▶ **Audit testing/data collection – Jan. 13-16, 2014**
- ▶ **Pre-submittal meeting (content) – Nov. 13, 2014**
- ▶ **Topical submittal to NRC – Feb. 27, 2015**
- ▶ **Post-submittal meeting – Today**
- ▶ **RAI – January 2016**
- ▶ **Additional meetings/technical audits – as needed**
- ▶ **Draft SE – August 2016**
- ▶ **Final SE – 4th Quarter 2016**

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ACE Correlation History(1)

- ▶ ACE correlation form developed between 2000 and 2005
- ▶ Development informally shared with U.S. NRC during visit to Richland in August 2003
 - ◇ Disclosed development of new fuel design
 - ◇ []
 - ◇ Preliminary results shown, to demonstrate the new correlation concept
 - ◇ []

ACE Correlation History(2)

- ▶ For a smooth regulatory review, it was suggested that the correlation development proceed in steps



ACE Correlation History(3)

- ▶ Later, Areva suggested that the NRC might want to attend the “short course on modeling and computation of multiphase flows” held in Zurich Switzerland
 - ◇ []
 - ◇ One member of NRC staff attended in 2005 and later brought the course in-house for other NRC staff members
- ▶ Informal meeting with NRC August 2005
 - ◇ First correlation to be submitted will apply to the ATRIUM 10 design
 - ◇ Significant progress in correlation development and behavior
 - ◇ Describe choices for constitutive models and basis for the modeling selection

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ACE Correlation History(4)

- ▶ April 2006 – informal meeting with NRC in Richland
 - ◇ Presented final correlation results
 - ◇ Statistics
 - ◇ Additive constants
 - ◇ []
 - ◇ Range of applicability
- ▶ ACE/ATRIUM 10 correlation topical report submitted May 2006 (ANP-10249P Rev. 0)
- ▶ Audit meeting held Oct. 31 – Nov. 2, 2006
- ▶ 38 RAI's covering the following topics

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ACE Correlation History(5)

- ◇ Range of applicability (4 questions)
- ◇ Submodels and fitting (12 questions)
- ◇ K-factor and additive constants (3 questions)
- ◇ Tested and production geometry (1 question)
- ◇ Safety limit (1 question)
- ◇ Correlation form (8 questions)
- ◇ Nodalization (2 questions)
- ◇ Implementation and application (1 question)
- ◇ Uncertainties and statistics (4 questions)
- ◇ Transients (1 question)
- ◇ Data base (1 question)

ACE Correlation History(6)

- ▶ Response to RAI's provided to NRC April 2007
- ▶ SE received August 2007

ACE Correlation History(7)

- ▶ **ACE/ATRIUM 10XM topical report (ANP-10298P Rev. 0) submitted to NRC December 2008**
- ▶ **Post-Submittal Meeting February 2009**
 - ◇ Topical report overview
 - ◇ KATHY test facility improvements
 - ◇ Features of ATRIUM 10XM that influence critical power
 - ◇ Critical power test program design
 - ◇ Differences between production and tested spacer
 - ◇ Database – including justification for data excluded

ACE Correlation History(8)

- ▶ **RAI's March 2009**
 - ◇ 7 Questions
 - ◇ Response to 6 RAI's provided June 2009
 - ◇ Response to remaining RAI provided August 2009
- ▶ **NRC Audit May 2009**
 - ◇ Main topic was differences between production and test assemblies
- ▶ **RAI's July 2009**
 - ◇ 15 Questions
 - ◇ Responses provided September 2009

ACE Correlation History(9)

► **The RAI's covered the following topics:**

- ◇ Differences tested/production assembly (8 questions)
- ◇ Range of applicability (2 questions)
- ◇ Statistics/trends (4 questions)
- ◇ Part length rods (1 question)
- ◇ Correlation submodels (3 questions)
- ◇ Correlation behavior/axial power shapes (2 questions)
- ◇ Transients (2 questions)
- ◇ Replicate data points/test procedure (1 question)

► **SE March 2010**

► [

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ACE Correlation History(10)

► **Error in reported power distribution of KATHY tests with part length rods**

- ◇ Additive constants revised
- ◇ ANP-10249P Rev. 0, Supplement 1 Revision 0 submitted July 2008
- ◇ No RAI's
- ◇ SE received September 2009

ACE Correlation History(11)

► K-factor deficiencies; improved K-factor method developed

- ◆ Supplements submitted Dec. 2011:
 - ANP-10249P Rev. 1, Supplement 1 Revision 0
 - ANP-10298PA Rev. 0, Supplement 1 Revision 0
- ◆ No RAI's on topical report supplements
- ◆ SE for both reports received March 2014

ACE/ATRIUM 11 Introduction

► Pre-submittal meeting – Aug. 12, 2010

- ◆ Introduction to features of ATRIUM 11
- ◆ Differences to ATRIUM 10XM
- ◆ Critical power correlation for ATRIUM 11 to be developed

- ◆ Invitation to attend critical power testing at KATHY loop

ACE/ATRIUM 11 Axial Power Shapes

- ▶ Pre-submittal meeting – Nov. 16, 2010



ACE/ATRIUM 11 Audit Critical Power Testing

- ▶ Audit testing/data collection – Jan. 29-Feb. 2, 2011
- ▶ Audit testing/data collection – Jan. 13-16, 2014
 - ◇ KATHY loop tour
 - ◇ KATHY loop data collection process
 - ◇ Show test hardware – spacers
 - ◇ Observe critical power test
 - ◇ Critical power correlation development process
 - ◇ Critical power test program
 - ◇ Quality assurance program
 - ◇ Critical power correlation form
- ▶ Information pertaining to some of these topics will be shown today

ATRIUM 11 Critical Power Test Program

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ATRIUM 11 112 Fueled Rods

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**ATRIUM 11
1/8 Symmetry**

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**ATRIUM 11
12 Short Part Length Rods**

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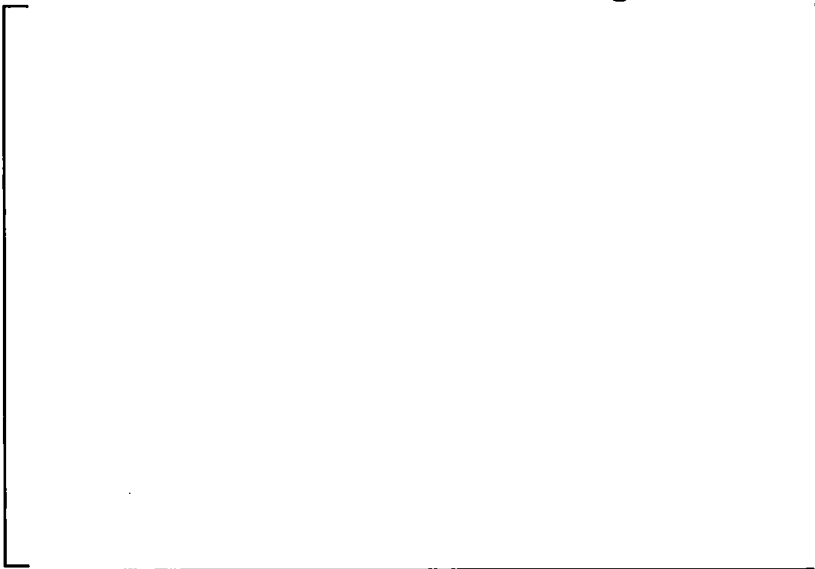
ATRIUM 11 8 Long Part Length Rods



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ATRIUM 11 Peaking Patterns




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ACE/ATRIUM 11


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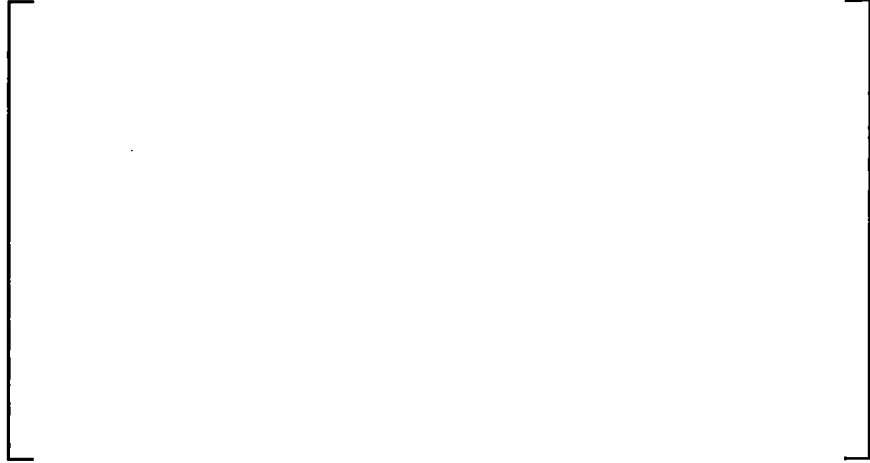
**ATRIUM 11
Performed Tests**



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ATRIUM 11 Tests By Region



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ATRIUM 11 Tests by Axial Shape



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ATRIUM 11 Data by Subgroup



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Critical Power Testing

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Changes For ATRIUM 11 Critical Power Testing (1)



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Changes For ATRIUM 11 Critical Power Testing (2)



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Changes For ATRIUM 11 Critical Power Testing (3)



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Quality Assurance in Testing

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QA Program Quality in Testing

- ▶ **Quality assurance is important**
- ▶ **A significant quality assurance program is in place**
 - ◆ Assures compliance with 10 CFR 50 Appendix B
- ▶ **Internal audits are performed to provide assurance that the work is performed to the expected standards**
 - ◆ Most recent audit of AREVA Technical Center Karlstein (KATHY loop testing) covering ATRIUM 11 testing was performed February 2012
- ▶ **Error reporting is also important**
 - ◆ 10 CFR 21 Notices posted, in German and English
- ▶ **In addition to global procedures for quality assurance, local procedures must also be satisfied**

QA Program Quality in Testing

- ▶ **Processes assure that records are collected and maintained**
- ▶ **Regular calibrations of instrumentation against standards**
- ▶ **Characterization of test hardware**
- ▶ **Inspections before and after test documented**

Correlation Development Process

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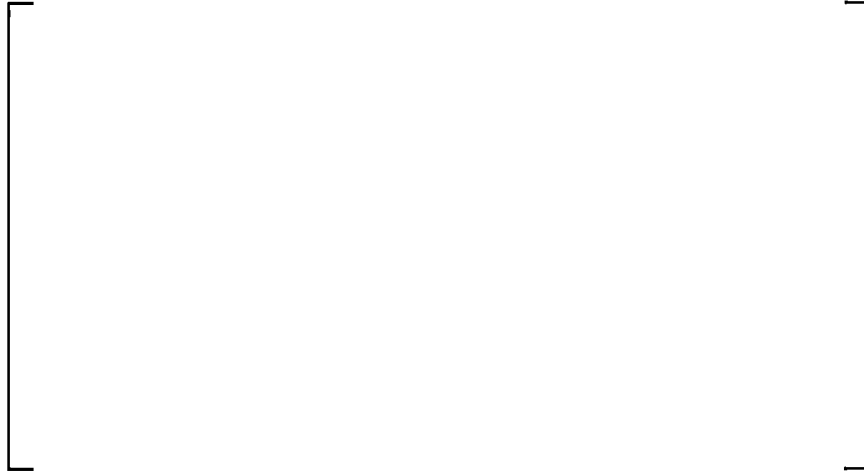
Correlation Development Process

- ▶ **Two facets of the critical power correlation development process:**
 - ◇ Procedural
 - ◇ Technical
- ▶ **The processes are formal**

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Procedural: []



Procedural: []



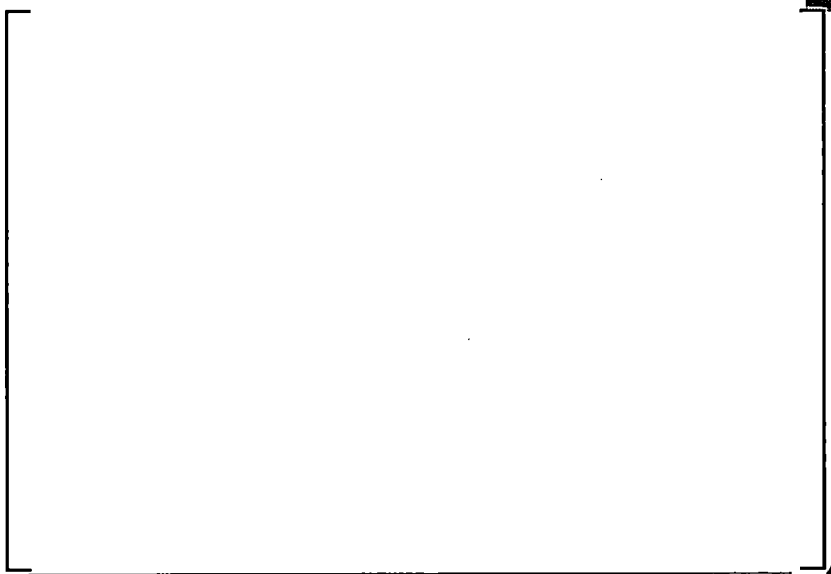
Technical: []



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Technical: []



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Topical Report Content

ACE/ATRIUM 11 Topical Report Content

- ▶ **The topical report content was discussed during the audit of KATHY and in the pre-submittal meeting.**
 - ◇ Agreed that the topical report would be stand-alone, with one exception
 - ◇ If the correlation form did not change, it would be referenced, since it was previously reviewed
 - The correlation form does not change for ACE/ATRIUM 11
 - ◇ The topical report has all of the necessary and agreed content
 - ◇ At the November pre-submittal meeting, it was agreed that the data points that fall outside the 95/95 value would be binned in the report – this has been provided

ACE/ATRIUM 11 Topical Report Content

- ▶ **Section 1: Introduction, intended application**
- ▶ **Section 2: Summary**
 - ◇ Key result: range of applicability table
 - ◇ Where reasonable, comparison to ATRIUM 10XM is provided in the report
- ▶ **Section 3: Regulatory requirements**
- ▶ **Section 4: Comparison of ATRIUM 11 design to ATRIUM 10XM design**
 - ◇ Comparison is limited to assembly attributes that have an influence on critical power
 - ◇ Key information: Axial zones identified (Figure 4.3)

Changes? Fuel Assembly Design

- ▶ **ATRIUM 11 is a new fuel assembly design. Compared to ATRIUM 10XM,**
 - ◇ Increase lattice size from 10x10 to 11x11

ACE/ATRIUM 11 Topical Report Content

- ▶ **Section 5: Comparison of ATRIUM 11 data base to ATRIUM 10XM data base**
- ▶ **Section 6.1: The ACE/ATRIUM 11 critical power correlation is presented**
 - ◇ Documentation is very similar to that from prior ACE correlations because the form of the correlation did not change
 - ◇ Key result: correlation coefficients

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Critical Power Correlation Form

- ▶ **ACE/ATRIUM 11 is third critical power correlation built on the ACE correlation form**
 - ◇ ACE/ATRIUM 10 (ANP-10249P-A Rev. 2)
 - ◇ ACE/ATRIUM 10XM (ANP-10298P-A Rev. 1)
- ▶ **Each of the three critical power correlations shares the same correlation form**
 - ◇ []
 - ◇ Form reviewed and approved in ANP-10249P-A
 - ◇ Form not changed for ACE/ATRIUM 11

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ACE/ATRIUM 11 Topical Report Content

► Section 6 continued...

- ◇ Method for determining additive constants is described. This method has some minor differences compared to prior correlations

- ◇ Key result: additive constants

- ⇒ Correlation behavior shown with respect to key independent variables

ACE/ATRIUM 11 Topical Report Content

► Section 6.13: Range of applicability – detailed discussion and justification

ACE/ATRIUM 11 Topical Report Content

► Section 7.1 examines the critical power correlation in the context of the defining data set

- ◇ Plot comparing measured to calculated critical power
- ◇ ECPR plotted as function of independent variables – mass flow rate, pressure, inlet subcooling, axial power shape, K-factor
- ◇ Overall statistics provided
- ◇ []
- ◇ Tabulated binned statistics of ECPR as a function of each independent variable
- ◇ ECPR statistics by test

ACE/ATRIUM 11 Topical Report Content

- ◇ Two variable ECPR statistics. The data are binned by
 - Mass flow rate and test
 - Mass flow rate and pressure
 - Mass flow rate and inlet subcooling
 - Pressure and inlet subcooling
- Section 7.2 examines the critical power correlation in the context of the validating data set
 - ◇ This data set was not used in the fitting of the coefficients
 - ◇ Overall statistics of each data set and the combined data set are provided
 - ◇ Plot comparing measured to calculated critical power
 - ◇ ECPR plotted as function of independent variables – mass flow rate, pressure, inlet subcooling, axial power shape, K-factor
 - ◇ Tabulated binned statistics of ECPR as a function of each independent variable
 - ◇ []

ACE/ATRIUM 11 Topical Report Content

▶ **Section 7.2 also provides**

- ▶ **Section 7.3 provides a benchmark of the ACE/ATRIUM 11 critical power correlation to ATRIUM 11 transient dryout measurements performed in the KATHY loop**

ACE/ATRIUM 11 Topical Report Content

▶ **Section 8 describes the data collected and the correlation predictions of that data**

- ◇ Axial power profiles
- ◇ Bundle radial power distribution
- ◇ Tests associated with each peaked rod position
- ◇ Tabulated experimental data
- ◇ Plots – critical power versus inlet subcooling and mass flow rate – with calculated and measured results

▶ **Section 9 discusses differences between tested bundle and the production fuel assembly design**

Test Assembly

► Test assembly differences from production assembly



ACE/ATRIUM 11 Conclusions

► The ACE/ATRIUM 11 critical power correlation can be approved because:

◇ [

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- ◇ The range of applicability is both sufficient and adequate
- ◇ The critical power correlation applies to all conditions that might be encountered within the range of applicability
- ◇ The correlation is conservative when applied to transients

Schedule

- ▶ Pre-submittal meeting – test program – Aug. 12, 2010
- ▶ Pre-submittal meeting – test axial power shapes – Nov. 16, 2010
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- ▶ RAI – January 2016
- ▶ Additional meetings/technical audits – as needed
- ▶ Draft SE – August 2016
- ▶ Final SE – 4th Quarter 2016

Next Steps RAI's and Technical Audit

- ▶ Process used in previous critical power correlation topical reports has worked well
- ▶ Preliminary RAI's provided and then an audit trip is scheduled
 - ◇ We prepare draft responses to all preliminary RAI's prior to arrival of reviewer(s)
- ▶ Preferred location for audit is Richland, WA, because
 - ◇ Discuss RAI's and draft responses; make sure that we understand the question; make sure the response we provide to the reviewer is what is intended to answer his/her question
 - ◇ Detailed documentation behind the topical report is available for inspection at this AREVA location; subject matter experts are available, if needed, to answer questions
 - ◇ Some hardware can be shown
 - ◇ New questions – try to address these prior to the completion of the meeting; resources to achieve this are available at this AREVA location
- ▶ When reviewer(s) leave, the draft responses to the questions are in hand; review is not delayed

Next Steps RAI's and Technical Audit

► If this plan is acceptable to you, it would be proposed that

- ◊ Preliminary RAI's (October 2015)
- ◊ Audit meeting (November 2015)
- ◊ Formal RAI's (Not later than January 2016)

Acronyms/Nomenclature

- BHL – Beginning of Heated Length
- BT – Boiling Transition
- ECPR – Ratio of calculated to measured critical power (C/M)
- FL – Full Length rod
- PLR – Part Length Rod
- SDE – Statistical Design of Experiments