AREVA

MOX Project Kickoff Meeting

Len Newman
AREVA MOX Program Manager

AREVA

Outline

- **MOX Project Overview**
  - **Project Background, History** — **Len Newman**
  - **Project Organizational Overview**
  - **AREVA Goals**
  - **Recent MOX Hot Cell Results** — **Dr. Kevin McCoy**
  - **Codes & Methods Task Overview** — **Chris Lewis**
    - BWR
    - PWR
  - **Project Schedule** — **Len Newman/ Chris Lewis**
    - Integrated Schedule
    - Topical Submittals (BWR and PWR)
  - **Future NRC Interaction**
    - Quarterly Status Updates
    - Codes & Methods Technical Sessions
    - Open Discussion (How can we make life simpler)

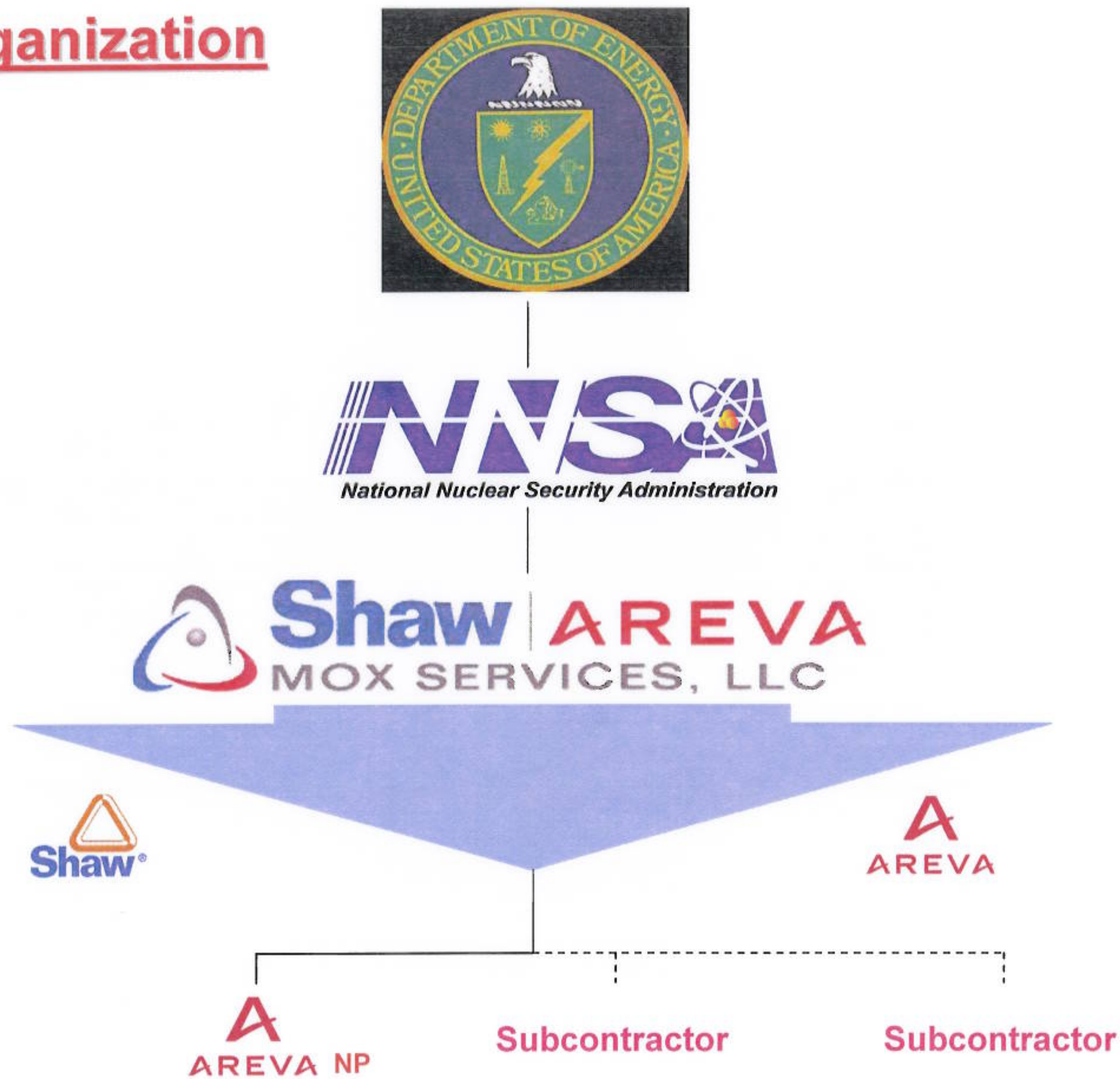
Project Background

- DOE MOX Mission
  - Convert 34 metric tons of weapons-grade plutonium to mixed oxide (MOX) fuel for irradiation in commercial power reactors
  - Implement international agreement with Russia where they will also dispose of 34 metric tons of surplus weapons-grade plutonium
  - MOX Fuel Fabrication Facility (MFFF) at the Savannah River Site (SRS) in Aiken, South Carolina manufacture the MOX fuel assemblies
    - Both BWR and PWR fuel fabrication is planned
  - See www.moxproject.com for more information
- Impact
  - Removes thousands of warheads from the nuclear arsenal
  - Eliminates $500 million / year in security costs
  - Provides clean, carbon free energy that offsets the use of over 26 billion pounds of coal

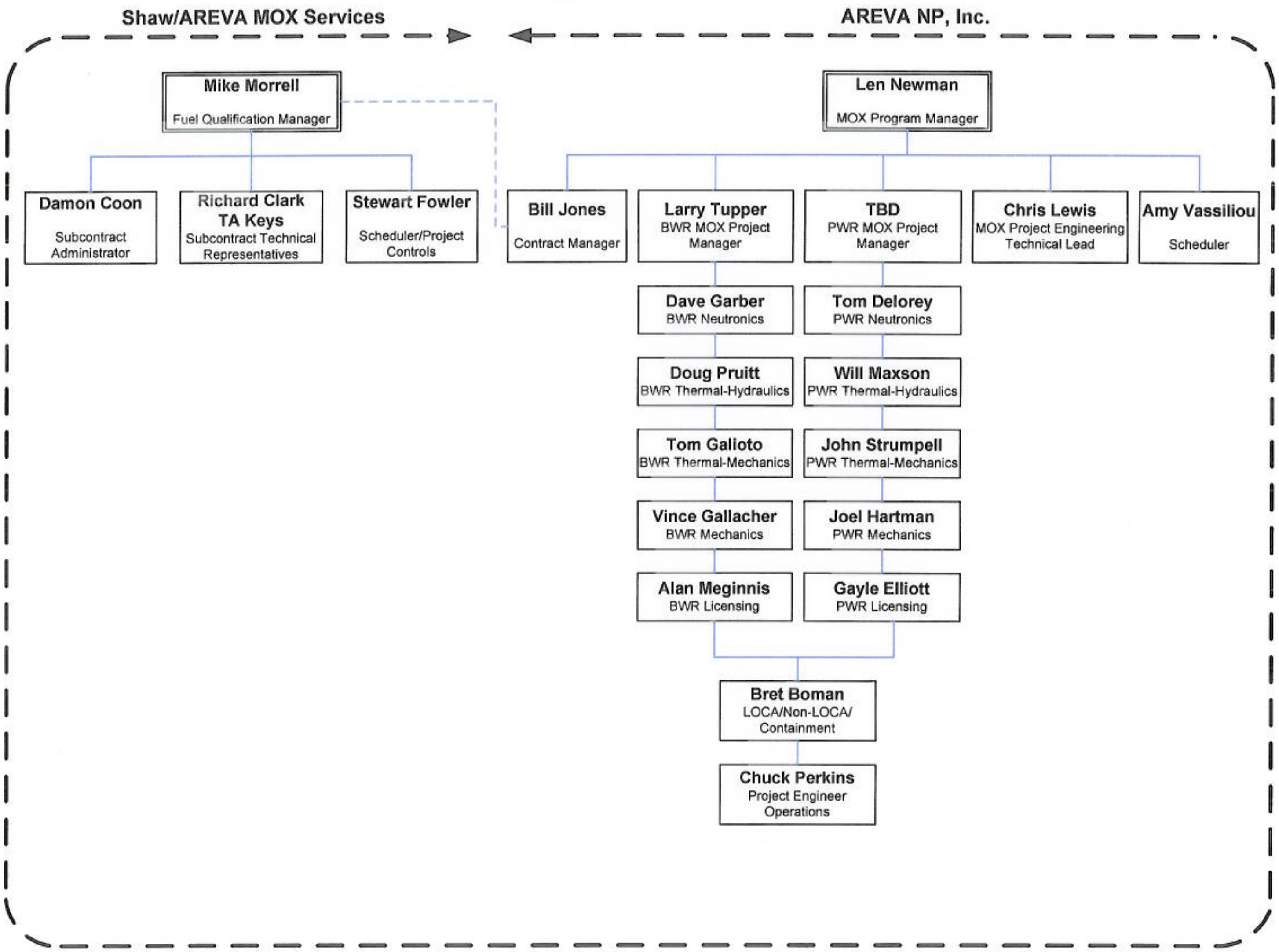
Project History

Early 1990's	Agreements put in place with Russia to dispose of equivalent amounts of warheads
1999	Contract was awarded to Duke Cogema Stone and Webster (DCS) to design and build the MFFF
2000	AREVA NP awarded a contract to qualify the fuel design for MOX
2005	Four Advanced MK-BW lead test assemblies (LTA's) were fabricated at MELOX and delivered to Duke's Catawba station
2007	Construction began on the MFFF
2008	LTA's were discharged after 2 cycles of operation due to growth issues (non-MOX related) Duke withdrew from the MOX program citing commercial reasons but still expresses interest in MOX Five rods from the LTA's were shipped to ORNL for hot cell evaluations
2009-11	Construction continues on the MFFF, hot cell evaluations continue, and AREVA NP continues analyses in support of MFFF under the current contract
Nov. 2011	Sub-contract let for AREVA NP to develop BWR MOX Licensing Methodologies and submit to the NRC for approval
Feb. 2012	Sub-contract let for AREVA NP to develop PWR MOX Licensing Methodologies and submit to the NRC for approval

MOX Organization



Organizational Overview



AREVA

Project Goals

- In support of this mission AREVA has been contracted by Shaw/AREVA MOX Services to:
  - License all BWR/PWR codes and methods necessary to support a LAR implementing MOX fuel in a Light Water Reactor
    - Be in a position to deliver fuel in late 2018
  - Provide LWR fuel qualification support for MFFF

- The MOX Irradiation Licensing Project will be conducted in two distinct phases
  - Phase 1: Develop of all BWR/PWR Topical Submittals through NRC acceptance for review
  - Phase 2: Interact with NRC through RAIs to achieve acceptance of the MOX licensing methodologies
  - MFFF support activities will proceed in parallel with both these phases

- Kickoff Meeting Goal:
  - Present MOX project scope at a non-proprietary and high level
  - Identify potential methodology issues
  - Establish basis for future closed proprietary technical sessions

Lead Assembly Irradiation for Qualification of MOX Fuel

Dr. Kevin McCoy
Advisory Engineer, FDM-AL

AREVA

Outline

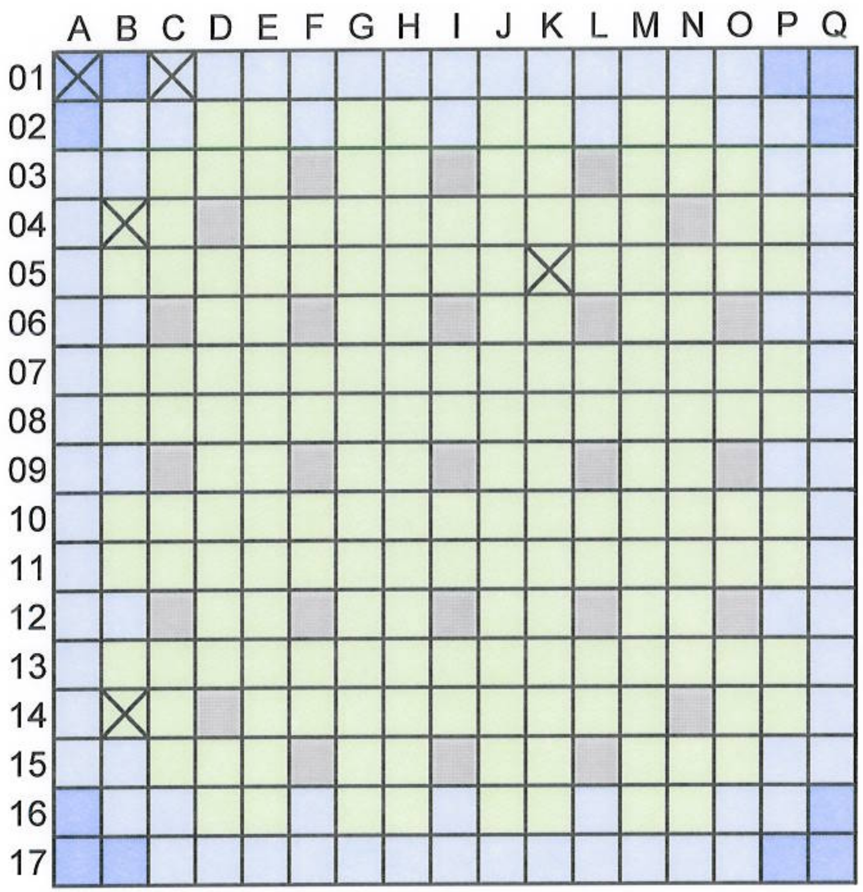
- Progress on lead assembly program
- Scope and extent of hot cell exams
- Sufficiency of exams in demonstrating fuel performance
- Basis for predicting WG-MOX fuel performance
- Future uses of the results

Lead Assembly Program Is Essentially Complete

- WG-MOX was considered to be a new fuel form
- Lead assemblies were fabricated at Cadarache and MELOX in France
- Fuel was successfully irradiated in Duke's Catawba Unit 1 for two 18-month cycles (June 2005 to May 2008)
- Fuel was thoroughly characterized
  - Measurement of as-built dimensions
  - Poolside examination after each cycle (Nov. 2006 and May 2008), reported in ANP-10280P, Rev. 2 (April 2009)
  - Hot cell examination of selected rods after second cycle, reported in ANP-10320P, Rev. 0 (Feb. 2012)

Aim was to confirm that the performance of WG-MOX is acceptable and can be predicted from previous experience with RG-MOX and LEU

Diverse Fuel Rods Were Selected for Hot Cell Examination



- ☒ = Selected for hot cell exam
- = Unfueled location
- = High-Pu location (4.94%)
- = Medium-Pu location (3.30%)
- = Low-Pu location (2.40%)

Rod-average burnups were 40 to 47 GWd/MT

Examinations Were Detailed and Thorough

- Nondestructive exams
  - Visual examination (5 rods)
  - Fuel rod length (5 rods)
  - Gamma scanning (5 rods)
  - Eddy current testing (5 rods)
  - Fuel rod profilometry (5 rods)

» **All results were consistent with safe and acceptable performance**

Examinations Were Detailed and Thorough

- Destructive exams
  - Gas pressure, void volume, and gas analysis (4 rods)
  - Optical microscopy of fuel and cladding (9 sections)
  - Transmission electron microscopy of cladding (5 irradiated samples plus 1 archival sample)
  - Scanning electron microscopy of fuel and cladding, radial burnup profile (5 samples)
  - Burnup determination (11 samples)
  - Isotopic analysis of fuel (11 samples; each analyzed for Cs, Ce, Nd, Sm, Eu, Gd, U, Pu)
  - Gallium analysis
    - Irradiated pellets (3 samples)
    - Archival cladding (2 samples)
    - Irradiated cladding (5 samples)

Examinations Were Detailed and Thorough

- Destructive exams (continued)
  - Cladding hydrogen analysis (7 irradiated samples plus 2 archival samples)
  - Mechanical testing of cladding (in progress)
    - Expanding plug testing
    - Axial tensile testing
  - Pellet density (5 samples)
  - Inspection of wear marks (1 rod survey plus 1 sample)
  - Cladding surface microscopy (1 sample)

» Again, all results were consistent with safe and acceptable performance

Hot Cell Results Indicate Safe, Acceptable Performance

- Results were generally as predicted or expected; variances from prediction are understood
  - Fuel rod and fuel stack growth were less than predicted but consistent with LEU experience
  - Water-side cladding oxidation and hydride concentration were less than predicted but consistent with LEU experience
  - Burnup of rod C-01 was larger than predicted; rod performance (e.g., gas pressure) was consistent with measured burnup
- No effects of gallium were found

» All results were consistent with safe and acceptable performance

Exams Are Sufficient to Demonstrate Fuel Performance

- Measurements not related to use of MOX (e.g., assembly growth are consistent with LEU performance
- Measurements related to use of MOX are consistent with predictions
- Exams satisfy commitments in BAW-10238PA, Rev. 1 with one exception: archival fuel pellets have not been analyzed for gallium
  - Concerns about gallium have been addressed by analysis of irradiated pellets, archival cladding, and irradiated cladding

There Is a Strong Basis for Predicting WG-MOX Fuel Performance

- Many AREVA RG-MOX (and RG-MOX + UO_2-Gd_2O_3) assemblies have been irradiated in Europe
  - > 5000 assemblies in 36 PWRs
  - > 900 assemblies in 3 BWRs
- Differences between RG-MOX and WG-MOX are considered
  - COPERNIC fuel rod performance code accounts for Pu concentration and its effects on thermophysical properties
  - Density of fissile atoms in Pu-rich agglomerates is similar in all MOX so local burnup is controlled
- Lead assemblies have been irradiated and examined to demonstrate performance of WG-MOX under U.S. irradiation conditions

» **WG-MOX performance predictions are supported by experience, modeling, and lead assembly data**

Hot Cell Results Can Be Used to Validate New Codes

- Measurements of fuel rod performance (e.g., gas pressure, diameter) can be directly compared to predictions from new codes
- When additional information about the lead assemblies' core becomes available, measurements can be compared with results from advanced neutronic and depletion codes

Summary and Conclusions

- The WG-MOX lead assemblies performed successfully
- Examination of the assemblies was detailed and thorough
- All results from examination of the lead assemblies were consistent with safe and acceptable performance
- Results from the hot cell exams, operating data for the lead assemblies, and AREVA's European MOX experience are a sufficient basis to qualify BWR and PWR licensing methods

BWR Codes and Methods Overview

Chris Lewis
MOX Engineering Project Lead,
Advisory Engineer, FD-A

AREVA

BWR MOX Codes & Methods

- **BWR MOX Fuel Design (Mechanical Design Topical)**
  - **Disposition Mechanical Methods with regard to MOX applications**
    - Purpose is to define the methodology (not a particular fuel design)
    - Will also reference the GALILEO Fuel Rod Code and Methodology
  - **Design a sample MOX fuel assembly**
    - ATRIUM-10XM Fuel Design
    - Including drawings, specifications, and BOM
    - Demonstrate the methodology
  - **Demonstrate compliance to mechanical design criteria**
    - Stress/Strain
    - Oxidation
    - Hydriding
    - Irradiation Growth
    - Internal Pressure
    - PCI
    - Etc.

BWR MOX Codes & Methods

- **BWR MOX Neutronics Methodology Topical**
  - **Incorporate MOX specific models into MICROBURN-B2 and CASMO-4**
  - **Perform additional benchmarking to MOX data (to complement current UO2 benchmarks)**
  - **Demonstrate capability to predict MOX and UO_2 performance**
  - **Establish calculation uncertainties (boron, power peaking, etc.)**
- **BWR MOX Reload Analysis Topical**
  - **Provide detailed description of the methods used to license a core design consisting of UO_2 and/or MOX fuel**
    - Process for evaluating neutronic parameters (i.e. MTC, Doppler, Scram Curves, delayed neutron fractions, etc.)
    - Evaluation of Chapter 15 Events
    - Provide benchmarking to MOX cores and develop MOX uncertainties

BWR MOX Codes & Methods

- **BWR MOX LOCA Methodology Topical**
  - **AURORA-B LOCA methods currently under development for UO2**
    - Extends AURORA models to include MOX
      - MOX Decay Heat
      - Ballooning
  - **Review and refine methodology assumptions with respect to MOX:**
    - Clad Swelling, Rupture, Fuel Relocation
  - **Develop sample problem and reactor benchmarks**

- **BWR MOX Stability Analysis**
  - **Assess impact on methodology due to following changes:**
    - MICROBURN-B2 updated for MOX
    - RODEX-4 replaced with GALILEO
  - **Assess the STAIF Reduced-Order fuel rod model and revise (as needed) to accommodate MOX**
  - **Extend the methodology with MOX cycle benchmarks**
  - **Present sample MOX applications**

BWR MOX Codes & Methods

BWR MOX DIVOM Methodology Topicals

- **Extend the RAMONA5-FA methodologies with MOX cycle benchmarks**
- **Assess impact on methodology due to following changes:**
  - MICROBURN-B2 updated for MOX
  - Qualified against GALILEO fuel rod performance
- **Perform MOX Cycle benchmarks**
- **Present sample MOX applications**

BWR MOX ATWS/Instability Methodology Topicals

- **Extend RAMONA5-FA DIVOM methods to include separate effect and reactor benchmarks not covered by the DIVOM project**
- **Present sample applications of the methodology to illustrate**
  - The impact of MOX on event progression and consequences
  - The acceptability of Emergency Plant Guidelines with regard to minimizing fuel failures

BWR MOX Codes & Methods

- **BWR MOX ATWS Methodology Topical**
  - **Extend AURORA-B methods beyond just peak vessel pressure criteria**
    - Address Boron injection and transport throughout the Rx vessel
    - Couple AURORA-B boundary conditions to a validated containment model
  - **Incorporate boron reactivity models into MICROBURN-B2 and MB2K**
  - **Develop MOX sample problems**

- **BWR MOX Containment Analysis Methodology Topical**
  - **Develop a new containment model and application methodology**
    - Based on GOTHIC code
  - **Benchmark the model(s)**
  - **Demonstrate application to containment acceptance criteria**
    - Pressure, temperature, containment overpressure credits, etc.)

PWR Codes and Methods Overview

AREVA

PWR Code & Methods Overview

- Topicals to be addressed:
  - PWR MOX Fuel Assembly Design Methodology
  - PWR Neutronics Methodology (ARCADIA®)
  - PWR Reload Analysis Methodology
  - PWR Rod Swap Methodology
  - PWR Rod Bow Methodology
  - PWR Power Distribution Control Methodology
  - PWR Fuel Assembly Reconstitution Methodology
  - Statistical Setpoint Methodology for Westinghouse Plants
  - Statistical Setpoint Methodology for CE Plants
  - PWR Fuel Rod Gas Pressure Criterion
  - PWR Rod Ejection Methodology
  - PWR Realistic LBLOCA Analyses Methodology
  - PWR Small-Break LOCA (SBLOCA) Analyses Methodology
  - PWR Non-LOCA Transient Analyses Methodology

PWR MOX Codes & Methods

- **PWR MOX Fuel Design (Mechanical Design Topical)**
  - **Disposition Mechanical Methods with regard to MOX applications**
    - Purpose is to define the methodology (not particular fuel design)
    - Will also reference the GALILEO Fuel Rod code and Methodology
  - **Design a sample MOX fuel assembly**
    - 17x17 HTP Fuel Design
    - Including drawings, specifications, and BOM
    - Demonstrate the methodology
  - **Demonstrate compliance to mechanical design criteria**
    - Stress/Strain, Oxidation, Hydriding, Irradiation Growth, Internal Pressure, etc.

PWR MOX Codes & Methods

- **PWR MOX Neutronics Methodology Topical (ARCADIA®)**
  - Incorporate MOX specific models into ARTEMIS and APOLLO2-A
  - Perform additional benchmarking to MOX data (complement current UO2 benchmarks)
  - Establish calculational uncertainties (boron concentration, and assembly, rod, and peak node power peaking)

- **PWR MOX Reload Analysis Topical**
  - Provide detailed overview of the methods used to license a core design consisting of UO_2 and/or MOX fuel
    - Focus on Westinghouse and CE Plant Designs
    - Includes any methods not specifically covered in specific topicals
  - Demonstrates the linkages and interactions between several other topicals used to perform reload licensing work
    - Define roadmap for reload analyses with all topicals
    - Revise automation codes that generate and move data between the specific reload methodologies

PWR MOX Codes & Methods

- **PWR MOX Rod Swap Topical**
  - **Describe method for determining reactivity worth of control rod groups/banks during startup**
    - Focus on Westinghouse and CE Plant Designs
    - Benchmarked against MOX Cycle Startups
  - **Incorporates change to ARCADIA® Neutronic methods**

- **PWR MOX Rod/Assembly Bow Topical**
  - **Include a review of the impact of MOX fuel on rod/assembly bow**
    - Effect of rod/assembly bow on 3D power distribution
    - Effect of rod/assembly bow on DNB and fuel centerline melt
    - Potential for fuel rod fretting
  - **Incorporates change to ARCADIA® Neutronic and COBRA-FLX TH methods**

PWR MOX Codes & Methods

- **PWR MOX Power Distribution Control Topical**
  - **Describes method for managing the core power distribution to protect power related SAFDLs**
    - Develops cycle operating strategies to maximize maneuvering flexibility
    - Demonstrates operating strategy can be effectively monitored with excore detectors
    - Impact of MOX on these strategies is evaluated
  - **Incorporates change to ARCADIA® Neutronic and COBRA-FLX TH methods**

- **PWR MOX Fuel Assembly Reconstitution Topical**
  - **Describes analytical method for evaluating the impact of replacing fuel rods in irradiated fuel assemblies including MOX fuel**
    - Evaluates the effect on assembly, rod, and nodal power distributions and subsequently on design criteria (DNB, CFM)
    - Includes use of inert (cold) and donor rod replacements
    - Establishes limitations on the number, type, and locations of potential replacement rods
  - **Incorporates change to ARCADIA® Neutronic and COBRA-FLX TH methods**
  - **Evaluates impact on Mechanical Design Criteria**

PWR MOX Codes & Methods

- **PWR MOX Statistical Setpoint Methodology Topicals**
  - **Describe methods to verify that complex reactor trip setpoints protect fuel design criteria during steady-state and transient operation**
    - Focus on Westinghouse (OPΔT, OTΔT) and CE (TM/LP, LPDs) plant configurations
    - Evaluates impact of MOX on uncertainties applied within methodology
  - **Incorporates change to ARCADIA® Neutronic and COBRA-FLX TH methods**

- **PWR MOX Fuel Rod Gas Pressure Criterion Topical**
  - **Describes revised fuel rod criterion**
    - Allows for operation of a small number of rods at internal rod pressures in excess of the nominal RCS pressure
    - Describe process for evaluating DNB propagation during accident conditions and any impact of MOX on propagation.
  - **Incorporates change to ARCADIA® Neutronic, COBRA-FLX TH and GALILEO TM methods**

PWR MOX Codes & Methods

- **PWR MOX Rod Ejection Methodology Topical**
  - Describes method for demonstrating compliance to NUREG-0800, Revision 3 interim guidance on criteria for control rod ejection accidents
  - Incorporates change to ARCADIA® Neutronic, COBRA-FLX TH and GALILEO TM methods
  - Incorporates MOX models and performs specific benchmarks for MOX
  - Identifies changes to the PIRT
  - Will build on the previously submitted Rod Ejection Methodology:
    - ANP-2788P

- **PWR MOX Non-LOCA Methodology Topical**
  - Incorporate MOX specific models into S-RELAP5
  - Reperform reactor benchmarks
  - Incorporates change to ARCADIA® Neutronic, COBRA-FLX TH and GALILEO TM methods
    - Use of 3D-coupled methods where appropriate

PWR MOX Codes & Methods

- **PWR MOX RLBLOCA and SBLOCA Methodology Topicals**
  - **Extends S-RELAP5 models to include MOX**
    - MOX Decay Heat
    - Ballooning
  - **Replaces RODEX-3/4 with GALILEO TM methods**
  - **Review and refine methodology assumptions with respect to MOX:**
    - Clad Swelling, Rupture, Fuel Relocation
  - **Develop a Long-Term Core Cooling Evaluation Model**
  - **Develop sample problem and reactor benchmarks**

Codes & Methods Implementation

Implementation Strategy

- **AREVA does not intend to maintain separate UO2 and MOX methodologies**
  - MOX topicals will start from current methods (Westinghouse/CE)
  - Update them accordingly to include MOX capability and address current NRC codes/methods issues
  - Ultimately replace old code/methods used on Westinghouse and CE plants
- **These topicals will address all lessons learned from the recent Calvert Cliffs and Browns Ferry LAR experiences**
- **AREVA wishes to continue a dialogue with the NRC to develop and submit these topicals in the most efficient manner**
  - From an AREVA development standpoint
  - From an NRC review standpoint
  - From an customer implementation standpoint

MOX Project Schedule

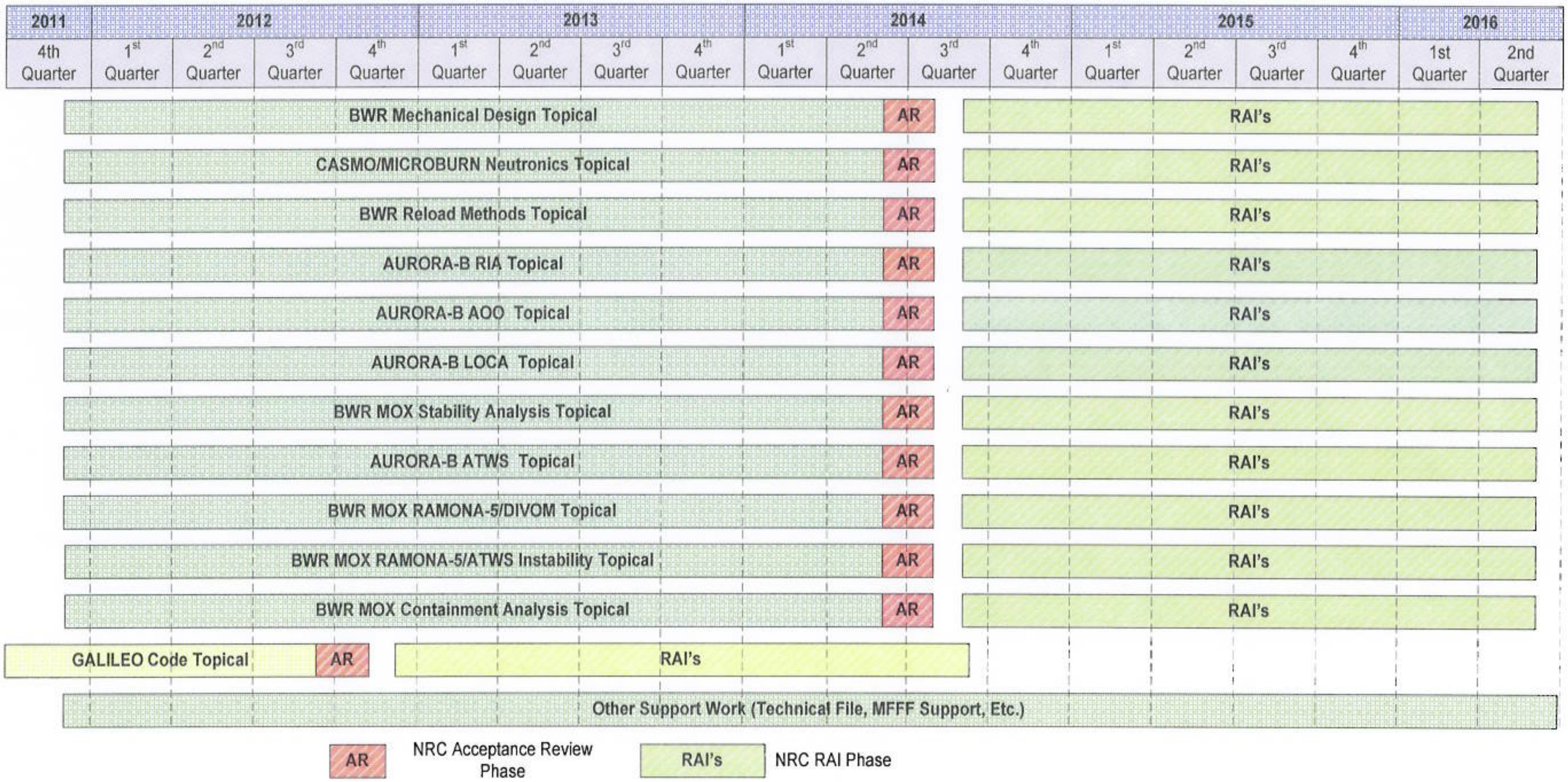
AREVA

MFFF Facility (August 2010)

MFFF Facility (December 2011)

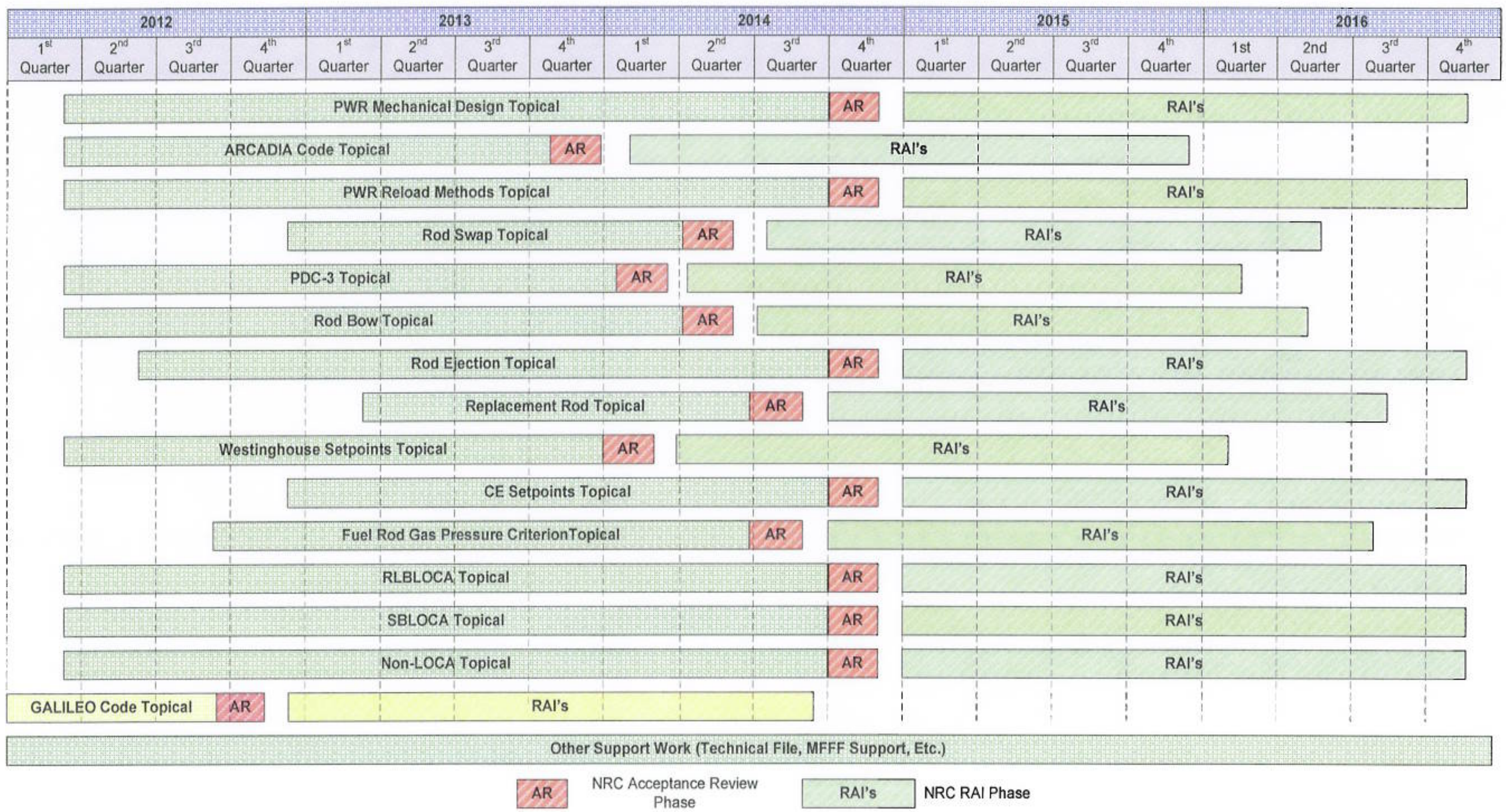
MOX Project Schedule

BWR MOX Topical Schedule

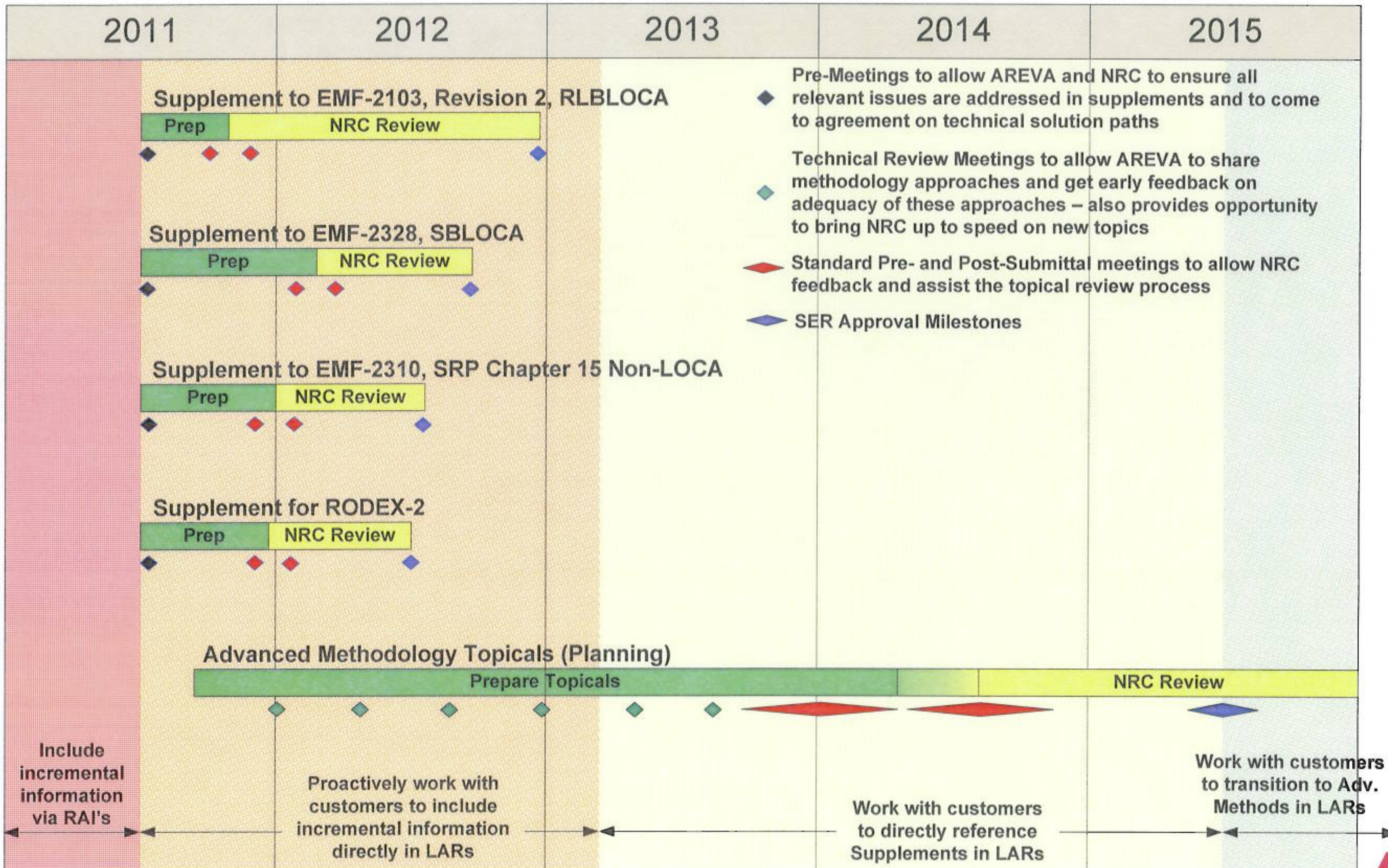


MOX Project Schedule

▶ PWR MOX Topical Schedule



Future NRC Interaction



AREVA

Future NRC Interaction

AREVA's Goal

Phase 1:

- Achieve maximum efficiency in this topical submittal process
  - Linked submittals
  - Standardized topical structure/formats
- Proactively address current NRC concerns regarding older codes & methodology
- Provide an early opportunity to familiarize staff with the technical material prior to the acceptance review phase
- Provide opportunities to respond to issues prior to the submittals

Phase 2:

- Achieve NRC approval of all licensing topical reports
- Qualify MFFF as a Fuel Fabrication facility for MOX Fuel

Future LAR:

- Initiate 1st LAR scope in late 2013
- Deliver 1st reload batch of MOX Fuel in late 2018