ACR-700 Physics Program
- Introduction -

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Presentation to US Nuclear Regulatory Commission

Rockville, MD

December 02, 2004

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Meeting Agenda

08:30	Introduction (NRC and AECL)
08:45	ACR Physics Program: Overview - Peter Boczar
09:15	Model and Code Assessment, Development and Verification (Hank Chow)
10:15	Break
10:30	ZED-2 Experiments (Peter Boczar)
12:00	Lunch
13:00	Code Validation (Hank Chow)
13:30	Path Forward: Pre-Application Transition Phase
14:00	Discussions (with a 15 min break at 14:30)
16:15	Opportunity for Public Comments
16:30	Closing Remarks
16:45	Adjourn

Meeting Objectives

- Provide an overview of the ACR-700 physics work program
- Discuss details of selected elements of the physics work plans
- Obtain NRC staff comments on the main elements of the physics program

Meeting Scope

- Provide elements and discuss details of the following areas
  - ACR-700 physics overall program and major milestones
  - ACR-700 physics model and code assessment and development
  - ACR-700 physics ZED-2 experimental measurements
  - ACR-700 physics code validation
- Discuss proposed AECLT-NRC interactions during the remainder of pre-application

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ACR Physics Program: Overview

Peter G. Boczar
Director, Reactor Core Technology Division, AECL

Presentation to US Nuclear Regulatory Commission
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Summary

- ACR physics program has been updated to reflect our experience and regulatory feedback over last 2 years
- Our assessments indicate that the current toolset is adequate for most aspects of core physics design
  - MCNP analysis for situations having significant spatial heterogeneity (such as checkerboard voiding)
- Physics toolset is being enhanced to capture heterogeneity between adjacent cells
- Validation program has been significantly expanded

ACR Physics Program Pertaining to Toolset Assessment, Development and Validation

B. ACR Physics Model and Code Assessment, Development and Verification

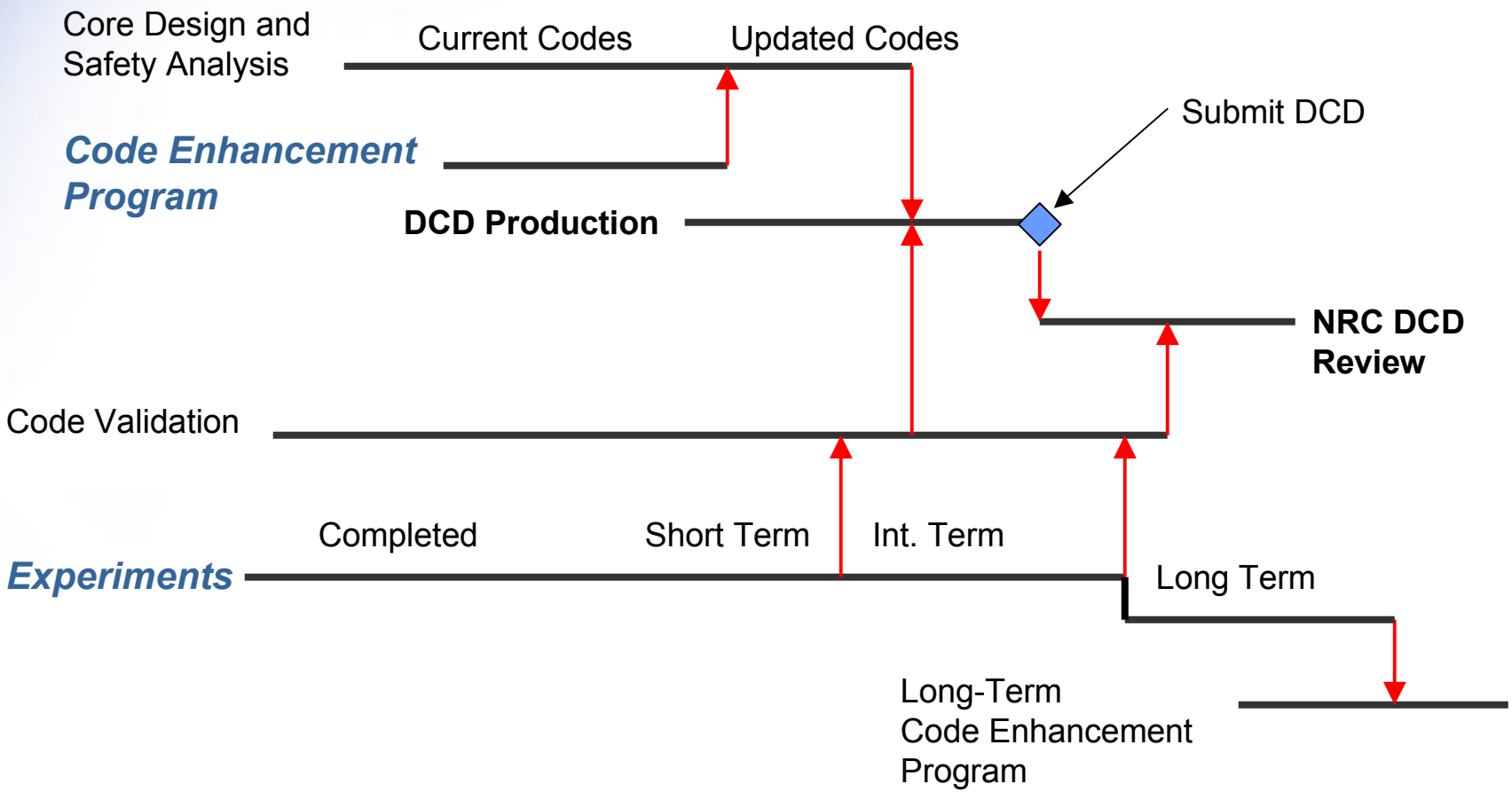
D. ACR ZED-2 Physics Measurements

E. ACR Physics Code Validation

Overview of Physics Program

- Status
  - scope is defined
  - addressing consistency of resource requirements, workscope and schedule
  - the program will be updated as required
- Program discussed in 2 phases
  - Near term: to support DCD preparation and submittal
  - Intermediate term: to support NRC review of DCD
  - Work will continue on toolset improvement and in understanding ACR physics in the longer term, through the nuclear platform R&D program

Approach to Reactor Physics Analysis



Changes to Workplan B: Model and Code Assessment, Development, and Verification

- Modification of toolset to account for heterogeneity
  - multi-cell capability is being implemented in WIMS 3.0, with enhancements to RFSP
  - for normal core configurations, applies to core-reflector interface, refueling transient
  - for abnormal core configurations, applies to LOCA transient analysis
- Additional independent assessment of ACR physics methods by Office of Chief Engineer (OCE)
- Coordinated Research Development (CRD) project with Ecole Polytechnique

Summary of Workplan B: Model and Code Assessment, Development, and Verification

- Near term
  - development of multi-cell capability in WIMS 3.0, and RFSP
  - revised Software Quality Assurance (SQA) documentation (Theory Manual, Users Manual, Verification Report, etc.)
  - formal release of enhanced WIMS and RFSP, for use by project for design and safety analysis
- Intermediate term
  - assessment / implementation of other approaches for addressing heterogeneity (such as nodal methods)

Changes to Workplan D: ACR-700 ZED-2 Physics Measurements

- Document suitability of ZED-2 for ACR physics validation
- More direct linkage of experiments with phenomena in validation matrix
- Increased number and type of experiments
- Addresses several specific issues
  - partial void measurements
  - measurements on several fuel types

Summary of Workplan D: ACR-700 ZED-2 Physics Measurements

- Near term
  - documentation of suitability of ZED-2 for ACR physics validation
  - performing key ZED-2 experiments with CANFLEX SEU to support code validation
    - CVR, checkerboard voiding, flux distributions (particularly at core/reflector interface)
- Intermediate term
  - completion of additional ZED-2 experiments

Changes to Workplan E: Code Validation

- In analysis of ZED-2 experiments, will significantly expand the analysis approach to include extensive modeling using WIMS/DRAGON/RFSP, and MCNP
  - direct, integral validation of these codes
    - reaction rates, reactivity, flux distributions
  - will provide validation data for physics toolset(s), as well as deriving validation data for cell code (WIMS)
- Validation of MCNP is emphasized
  - MCNP remains key in extending results from critical facilities (ZED-2, DCA) to ACR-700 conditions

Summary of Workplan E: Code Validation

- Near term
  - completion of validation reports for:
    - (a) experiments already performed with existing fuel under ACR-700 conditions,
    - (b) new experiments with CANFLEX SEU reference fuel, and
    - (c) experiments from other critical facilities
    - for validation of WIMS/DRAGON/RFSP toolset, and MCNP
  - production of ACR Physics Validation Manual
    - based on analysis of ZED-2 experiments, other experiments, and MCNP for extrapolation
    - establish estimate of bias and uncertainty in key physics parameters
- Intermediate term
  - validation reports for remaining ZED-2 experiments
  - update ACR Physics Validation Manual

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B: ACR Physics Codes and Models Assessment, Development and Verification

Hank Chow
Senior Physicist, Reactor Core Physics Branch, AECL

Presentation to US Nuclear Regulatory Commission
Rockville, MD
December 02, 2004

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Introduction

- This part of the program
  - assesses the suitability of the models and codes for ACR-700 physics
  - improves the reactor physics toolset for application to ACR-700
- Enhancements to the reactor physics toolset are being made to address the issue of heterogeneity between adjacent channels
  - core-reflector interface
  - refueling transient
  - LOCA analysis

Outline

- B.1 ACR Physics Code and Model Assessment
  - B.1.1 Infinite-lattice approximation and environment effects (WIMS)
  - B.1.2 Super-cell methodology for device incremental XS calculations (DRAGON)
  - B.1.3 2-group, finite difference diffusion theory for reactor core analysis (RFSP)
  - B.1.4 CVR in various core states
  - B.1.5 CVR sensitivity and CVR components
  - B.1.6 Analysis methodology for ACR substitution experiments
  - B.1.7 Effective delayed neutron fraction
  - B.1.8 Independent assessments
- B.2 ACR Physics Code Development and Verification
  - B.2.1 WIMS 3.0 development and verification
  - B.2.2 RFSP development and verification

B.1.1 Infinite-Lattice Approx. and Environment Effects

- Conventional approach of generating lattice-cell (WIMS) properties with net zero neutron currents at cell boundary (infinite lattice array)
  - ACR design - much tighter coupling with neighboring cells
  - lattice cell properties are now more affected by the environment
- Situations where environment effects are important
  - reflector / core boundary
  - defueled channel as a neighbor (refueling transient)
  - checkerboard void pattern in LOCA transient
- Multi-cell modeling will be used to assess environment effects and incorporate such effects in lattice-cell properties
  - situation-specific models will be used
  - in near-term, assessment will ascertain acceptability, and uncertainties associated with enhanced toolset
  - in intermediate term, assessments could drive further improvements in the toolset

B.1.2 Super-Cell Methodology - Device Representations

- Traditional super-cell methodology (DRAGON)
  - 3-D transport code used to model device and associated lattice, to calculate incremental XS
  - 2 L.P. x 1 L.P. x 1 bundle model
  - 89-group collapsed to 2-group
  - mid-burnup fuel, cooled lattice
- Assessing application to ACR
  - sensitivity to neighboring fuel burnup
  - sensitivity to cooled and voided neighboring cells, checkerboard void lattice
  - adequacy of 2-group representation in full-core calculations

B.1.3 Full Core Modeling Assessments

- RFSP based on 2-group, finite-difference diffusion theory
- Adequacy of 2 groups assessed against multi-group DONJON code
- Studies to date have identified improvement to analysis approach (selective use of multi-cell cross sections in WIMS/RFSP)
  - focus will be on implementation of these improvements in WIMS/RFSP (B.2.)
  - study of alternate approaches (below), not required for DCD, will take place in intermediate term
- Alternate approaches to 2-group, finite difference diffusion theory (in intermediate term)
  - Multi-group nodal flux solution method
    - first in 2 groups, then in multi-group
    - assembly discontinuity factor (ADF) inherent in nodal solution formulation
    - lattice-cell properties from WIMS and device representations in multi-group form from DRAGON (already possible up to 89-groups)
  - Other approaches

B.1.4, B.1.5 CVR-Related Assessments

- Full-core void and checkerboard CVR comparisons with MCNP
- CVR in various core states
  - applicable core states within operating envelope: low power, low temperature, poisoned moderator, startup after a long shutdown, tilted flux shapes, …
- CVR sensitivity to variations of design parameters
  - enrichment, Dy content, moderator purity, moderator poison, pressure tube creep, …
- Component contributions to CVR
  - actinides and Dy isotopes contribution to CVR as a function of fuel burnup, leakage, spectrum in lattice cell (in both cooled and voided lattices, uniform and checkerboard voiding)

B.1.6 Analysis Methodology for ACR Substitution Experiments

- Greater use will be made of direct modeling of ZED-2 experiments using WIMS/RFSP and MCNP
  - direct validation of fine structure, global flux distributions, reaction rates, reactivity
- Traditional approach will continue to be used of deriving buckling and buckling-change-upon-coolant voiding from substitution experiments, for direct validation of WIMS
  - plan to develop
    - improvements to the current methodology (CONIFERS)
    - alternate approaches to deriving buckling
- Accuracy of substitution analysis methodology for ACR experiments will be determined in Workplan E (validation)

B.1.7 Effective Delayed Neutron Fraction

- Delayed neutron precursor concentrations at each bundle position computed according to fission rates of each fissile isotope
- All delayed neutrons appear as fast neutrons in 2-group representation – actual energy distribution not modeled hence spectral importance lost
- An effective core-average beta value can be obtained with multi-group formalism and proper spectral weighting

B.1.8 Independent Assessments

- Adequacy of the improved calculational approach will be assessed through independent assessments
  - Collaborative Research Development (CRD) program with Ecole Polytechnique (EP), AECL, and Natural Sciences and Engineering Council of Canada (NSERC)
  - AECL's Office of Chief Engineer (OCE) will continue its own independent assessments using MCNP
  - independent assessments contracted by OCE outside of AECL using alternate toolset

CRD Project with University of Montreal Ecole Polytechnique (3-year program)

- **Proposed activities:**
  - ZED-2 reactor model using DRAGON/DONJON
  - ACR model using DRAGON/DONJON
  - comparisons with WIMS/RFSP results
  - environment dependent lattice properties
  - CVR
  - loss of coolant accident
  - nodal methods, discontinuity factors and kinetics analysis
  - fuel management optimization in DONJON
  - multi-parameter reactor database
  - improvement to TRIVAC flux solution operators in DONJON
  - improvement of resonance self-shielding model in DRAGON
  - improvement of geometry modeling in DRAGON

OCE Independent Reactor Physics Assessments

- Senior technical review of ACR physics documents, plans and results of ZED-2 experiments and code development/qualification activities
- Assessments of alternate fuel and non-fuel design options to address physics issues (e.g., checkerboard coolant void reactivity, refueling perturbation, end-flux peaking, burnable poisons)
- Influence of nuclear data and alternate data libraries, model assumptions
- Develop and implement (with the aid of consultants) a plan to:
  - identify and acquire an alternate ACR physics code set (including capable external consultants and resources)
  - define and execute a set of code-to-code benchmark comparisons

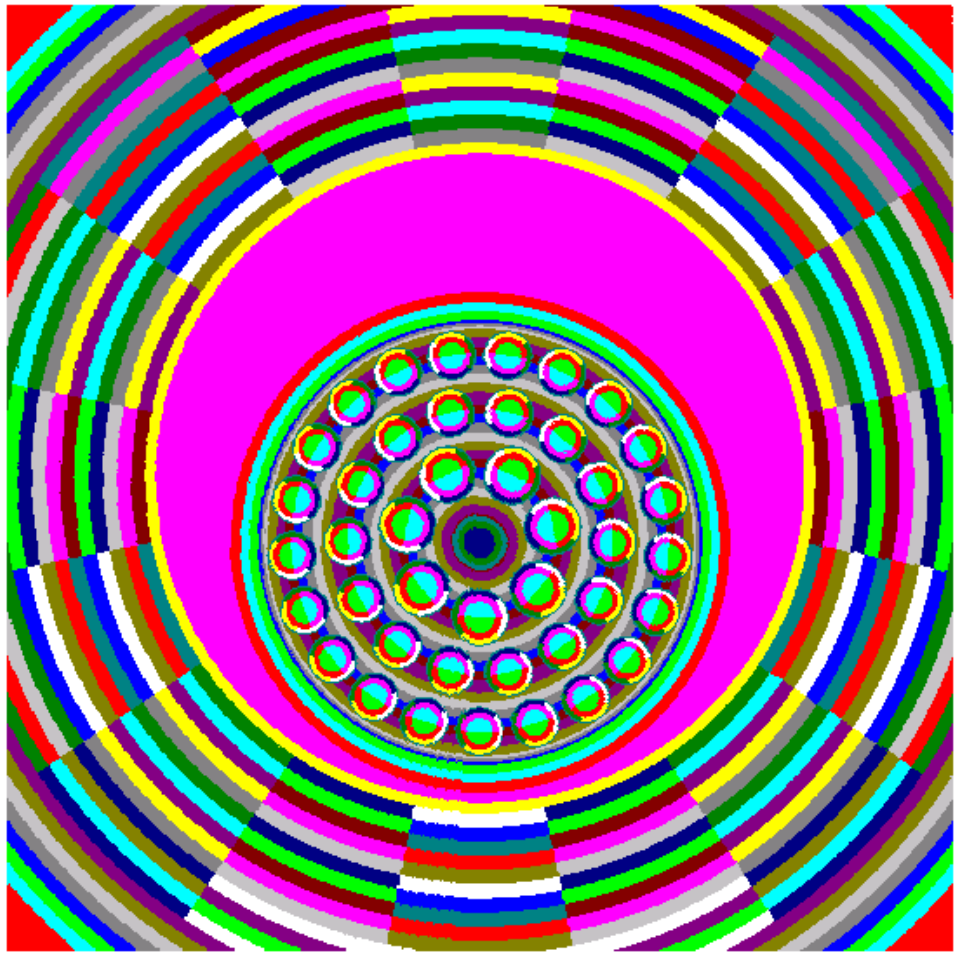
Independent Assessment Using Alternate Toolset

- Sponsored by OCE
- Software Problem Definition document and Software Requirement Specification document prepared
- Process initiated to identify suitable independent toolset
  - not been used in ACR design process
  - organization supplying codes with infrastructure to provide initial training, ongoing code development and customer support
- Assessments cover key nuclear design characteristics, e.g.:
  - power and flux distribution
  - linear element rating
  - void coefficient, temperature coefficients
  - accident transients
  - fueling and core-follow application
- Assessment performed by independent contractor (and/or in-house in OCE)

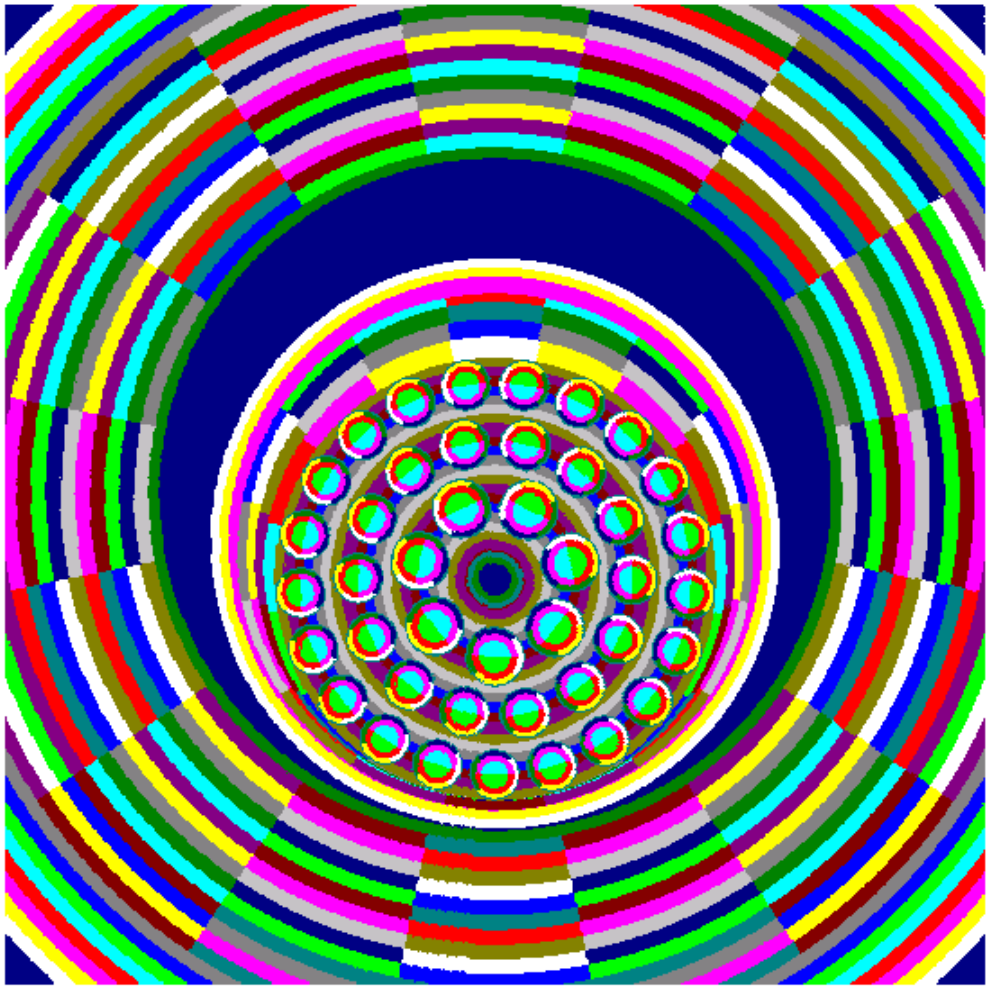
B.2.1 WIMS 3.0 Development and Verification

- WIMS 3.0 (beta) released for testing
  - improved resonance treatment
  - more detailed geometrical representation
- Multi-cell capability being developed
- Verification
  - comparisons to MCNP (both integral and separate effects)
    - see presentation from 2004 July 26 meeting at CRL (D. Altiparmakov, "Enhancements to the WIMS Code")
  - other [such as selective code walk-through, analysis using CASE tools (FLINT, HINDSIGHT, FORCHECK)]
- Revised SQA documentation, including
  - Theory Manual
  - Users Manual
  - Verification Report

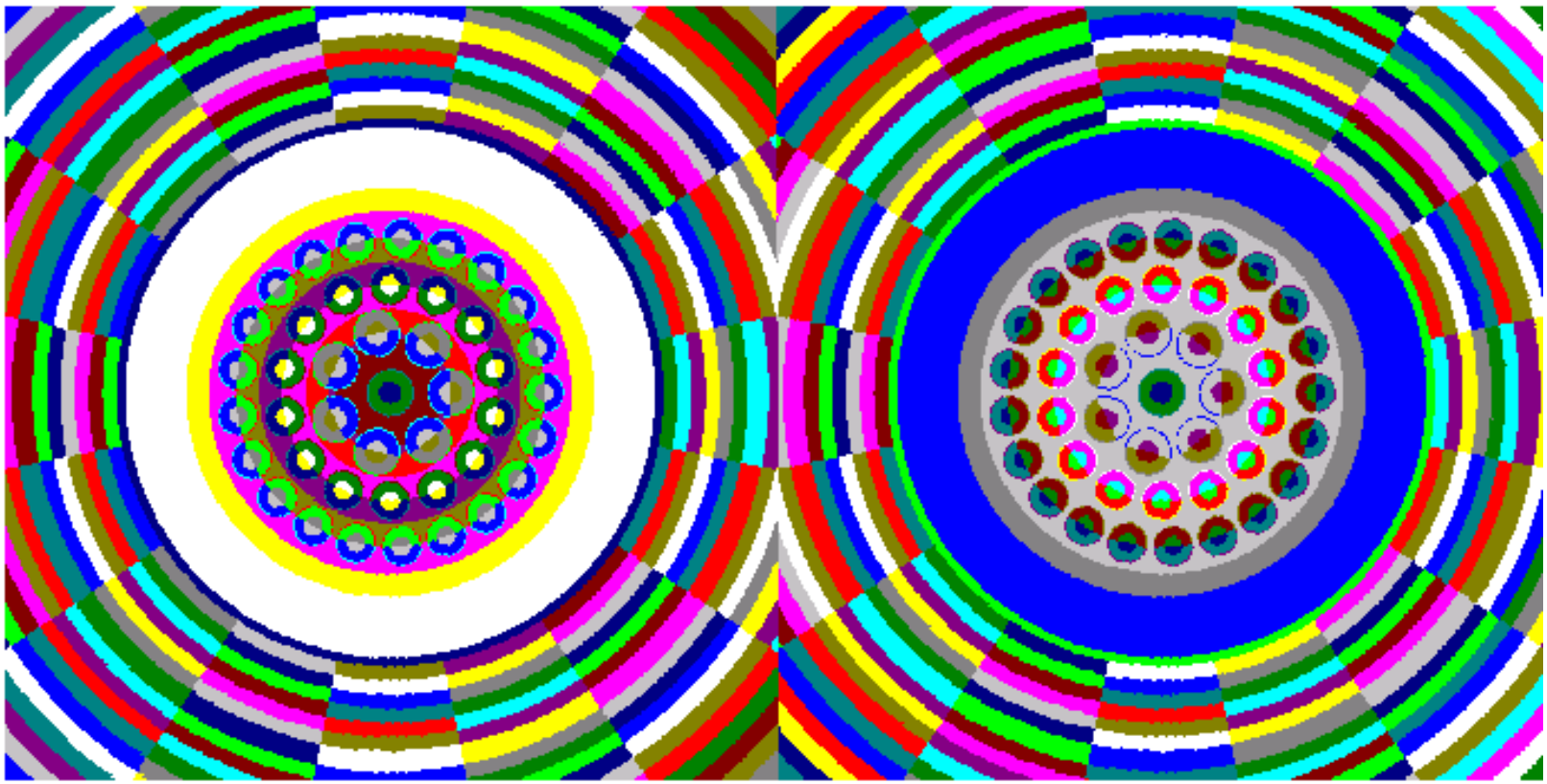
Pressure Tube Sag



Pressure Tube Creep and Sag



Multi-cell Capability



B.2.2 RFSP Development and Verification

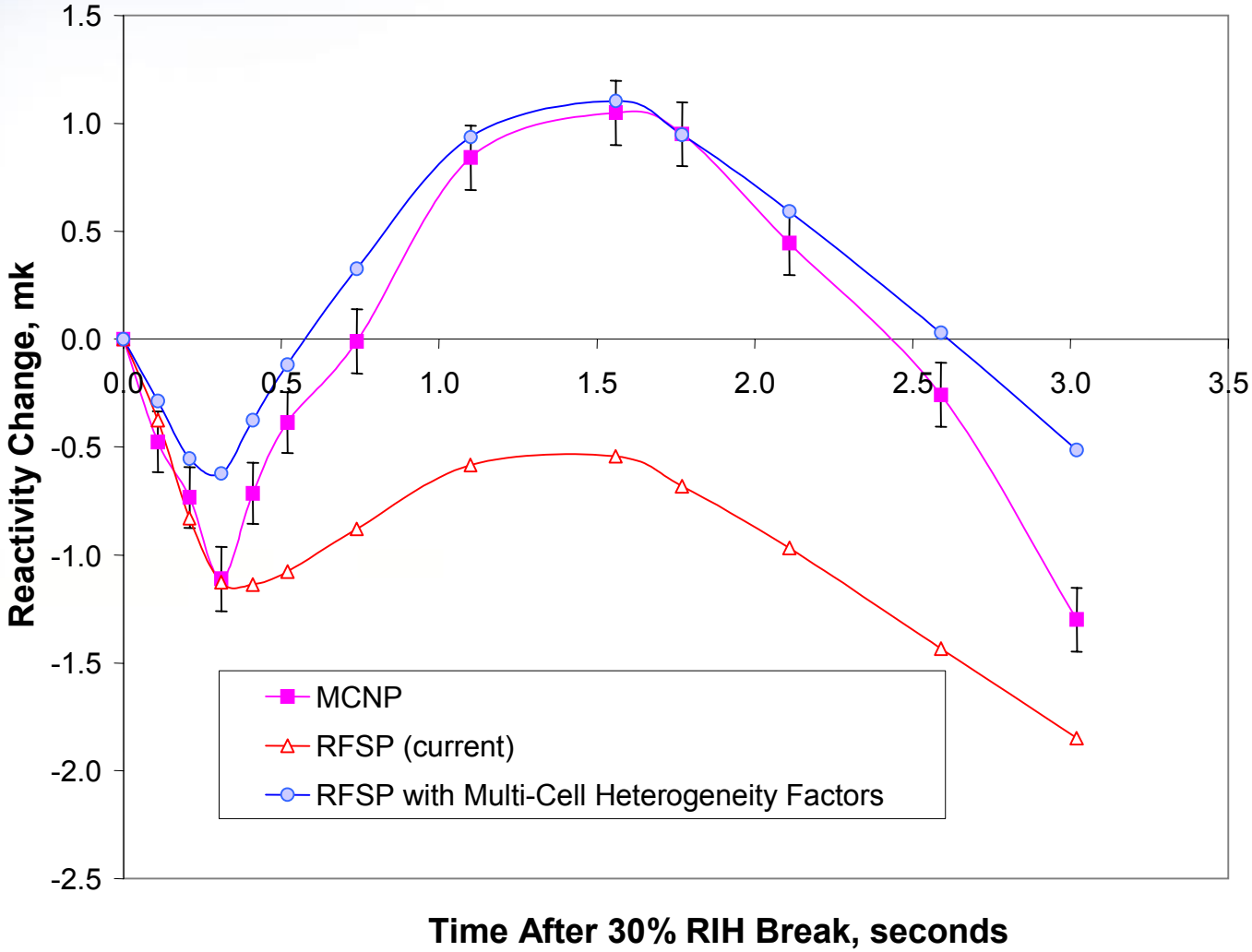
- Micro-depletion model has been implemented and is currently being verified and validated
  - for isotopic evolution calculations (burnup reflecting local parameters and history)
- Implementation of multi-group cross sections from WIMS to account for heterogeneity is currently being implemented in WIMS 3.0 and RFSP (including CERBERUS for kinetics)
  - core/reflector interface
  - H_2O-cooled channel during refueling
  - checkerboard core modeling

Modeling Checkerboard Voiding with CERBERUS with Multi-Cell Cross Sections

- Heterogeneous parameters:
  - coolant density, fuel burnup, fuel temperature
- Pre-calculated infinite-lattice WIMS fuel tables
  - a function of burnup, at 2-D grid points of coolant density and fuel temperature (using single lattice-cell models)
- Pre-calculated Heterogeneity Factors
  - function of average coolant density difference and fuel burnup difference (using 2x2 multi-cell models) with neighboring cells
- RFSP (CERBERUS) adjusts the infinite-lattice XS using the Heterogeneity Factors corresponding to the average coolant density and fuel burnup of the 4 neighboring cells, at each step in the transient
- Preliminary results for 30% Reactor Inlet Header (RIH) break case
  - next overhead, calculated with multi-cell cross sections from DRAGON rather than WIMS)

RFSP Reactivity Changes at Snapshots during 30% RIH LOCA

With Multi-Cell Heterogeneity Factors; No shutdown



ACR Physics Analysis Approach

- Current toolset adequate for most core configurations
- Will use WIMS 3.0 with enhancements to RFSP for ACR physics design and safety analysis
  - multi-cell treatment of
    - core-reflector interface
    - refueling transient
    - LOCA analysis
- Modeling uncertainties assessed through specific detailed MCNP analysis
  - bundle powers / channel powers in steady state
  - reactivity, powers during LOCA

Summary

- Assessment of codes and models has identified improved approach for addressing heterogeneity. Will continue to look at:
  - infinite-lattice approximation
  - CVR sensitivities
  - full core flux / power calculation accuracy, including checkerboard void configurations
- Several initiatives to provide independent assessment of ACR physics analysis

Summary (cont'd)

- Toolset is being enhanced for application to ACR-700
  - WIMS 3.0 has significant improvements in geometrical and resonance treatments
  - micro-depletion method incorporated into RFSP will give improved burnup treatment reflecting local parameters
  - multi-cell capability in WIMS and RFSP will allow treatment of environment effects (heterogeneity) where necessary

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D: ACR ZED-2 Physics Measurements

Peter Boczar (for Mike Zeller, Head, ZED-2 experimental section)
Director, Reactor Core Technology Division

Presentation to US Nuclear Regulatory Commission

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Introductory Comments

- Historically, ZED-2 measurements have provided data for validating lattice codes (e.g., WIMS-IST)
  - full-core flux maps and substitution experiments used to derive a materials buckling for a test lattice
    - bucklings used for direct comparison to lattice code predictions
  - fine-structure measurements (for direct comparison to lattice code)
- For ACR, broader analysis approach is planned
  - as well as validation of WIMS directly against buckling from full-core flux maps and substitution experiments, and fine-structure, will add
  - direct validation of WIMS/RFSP against ZED-2 experiments, using a similar modeling approach as planned for ACR
    - reaction rates, reactivity, flux distributions
- MCNP will also be directly validated against ZED-2 measurements

Outline of Plan

D.1 CNSC approval and Facility Authorization (FA) for use of SEU reference fuel in ZED-2

D.2 Revised ZED-2 experimental plan

D.3 Description of planned key experiments with sufficient detail to allow pre-analysis

D.4 Initial measurements (using CANFLEX SEU reference fuel)

- D.4.1 Checkerboard voiding using CANFLEX SEU reference fuel
- D.4.2 CVR for square lattice with 12 channels of CANFLEX LVRF
- D.4.3 Full core flux maps
- D.4.4 Moderator temperature reactivity coefficient
- D.4.5 Moderator poison reactivity coefficient
- D.4.6 Documentation of suitability of ZED-2 for ACR physics validation

Outline of Plan

D.5 Subsequent measurements

- D.5.1 Checkerboard partial void with CANFLEX SEU and CANFLEX LVRF in square lattice
- D.5.2 Uniform partial void with CANFLEX SEU, CANFLEX LVRF and CANFLEX MOX in hex lattice
- D.5.3 High temperature CVR with CANFLEX LVRF and CANFLEX MOX
- D.5.4 CVR, checkerboard void, and partial coolant void in square lattice with 12 channels containing CANFLEX MOX
- D.5.5 Substitutions of CANFLEX SEU into a ZEEP reference lattice
- D.5.6 Substitutions of 37-element LVRF into SEU reference lattice
- D.5.7 Substitutions of CANFLEX LVRF into SEU reference lattice
- D.5.8 Substitutions of 37-element MOX into SEU reference lattice
- D.5.9 Substitutions of CANFLEX MOX into SEU reference lattice

Outline of Plan

D.5.10 Standard fine structure (CANFLEX LVRF and CANFLEX MOX)

D.5.11 Fine structure in central checkerboard lattice with CANFLEX LVRF and CANFLEX MOX

D.5.12 Fine structure in checkerboard lattice at core/reflector interface

D.5.13 Fine structure with H2O-filled channel

D.5.14 End-flux peaking with CANFLEX LVRF

D.5.15 Rod drop measurements into uniform lattice of CANFLEX SEU fuel

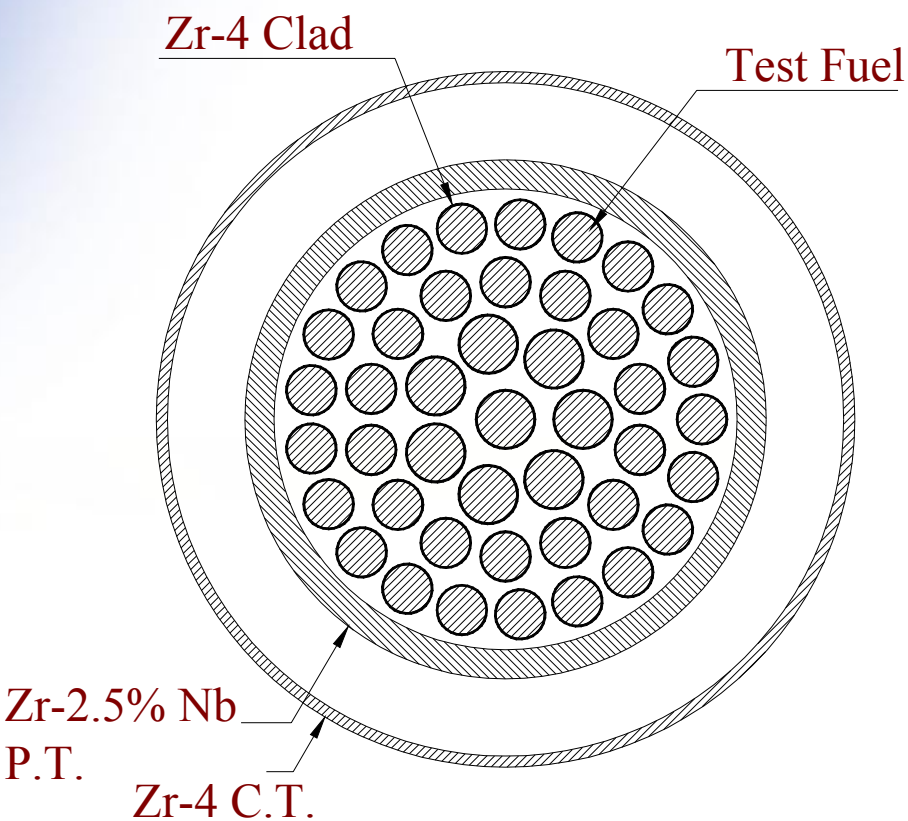
D.5.16 Reactivity worth measurements of control devices (mechanical control absorber, shut-off rod), using period measurement

D.5.17 Down graded moderator experiments

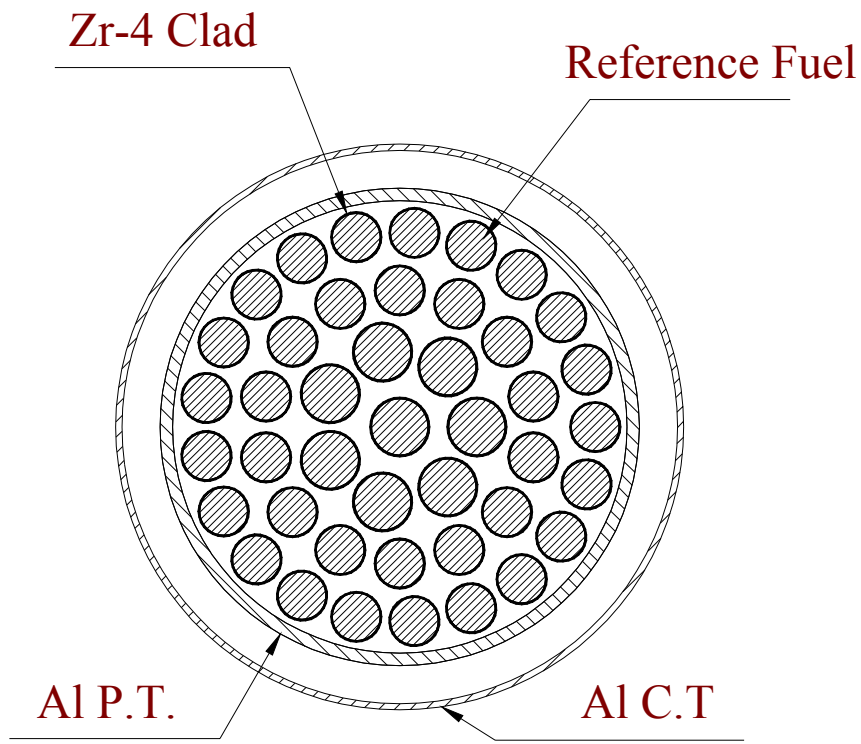
D.5.18 Flux detector response measurements

ACR-Type Test Channel and CANDU-Type Reference Channel

ACR-Type Channel



CANDU-Type Channel



Test Fuel Isotopics

37-Element LVRF	U^{235}/U (wt%)	Dy/U (wt%)
Outer Ring	1.35	0.0
Middle Ring	1.92	0.0
Inner Ring	0.36	2.0
Center Pin	0.36	10.0

CANFLEX MOX	U^{235}/U (wt%)	Pu/U (wt%)	Dy/U (wt%)
All Outer Rings	TBD	TBD	0.0
Center Pin	TBD	TBD	TBD

CANFLEX LVRF	U^{235}/U (wt%)	Dy/U (wt%)
All Outer Rings	1.0	0.0
Center Pin	0.71	15.0

CANFLEX SEU (reference fuel)	U^{235}/U (wt%)	Dy/U (wt%)
All Rings & Center Pin	0.95	0.0

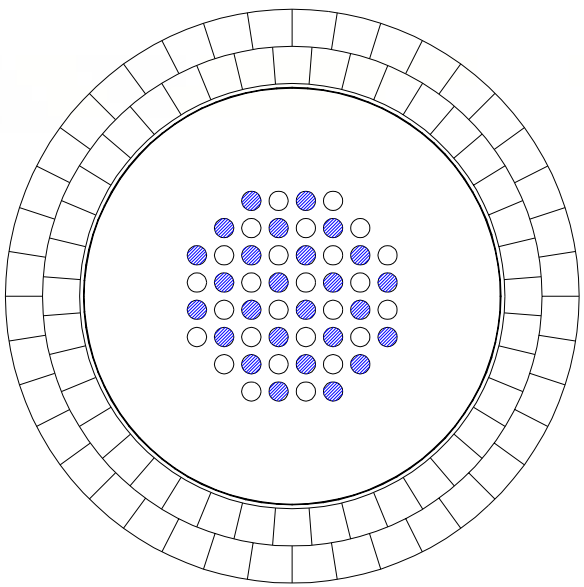
(D.4.1, D.4.2)

CVR Measurements Including Checkerboard Voiding

- 52-rod CANFLEX SEU square lattice with both uniform and checkerboard void distributions
- flux measurements in the reflector

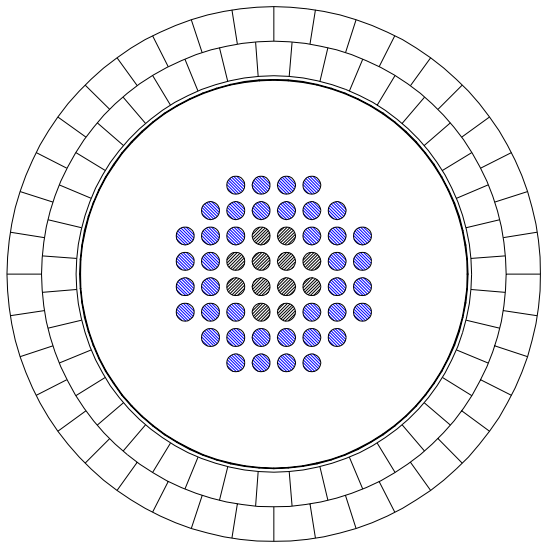
Checkerboard Void CANFLEX SEU Lattice

- Air Coolant
- Light Water Coolant



12-Channel CANFLEX LVRF Lattice

- SEU Driver Channel
- LVRF Test Channel



- Square lattice containing 12 channels of CANFLEX LVRF located in the center of the lattice, driven by surrounding channels of CANFLEX SEU
- uniform and checkerboard voiding

(D.4.3 - D.4.5)

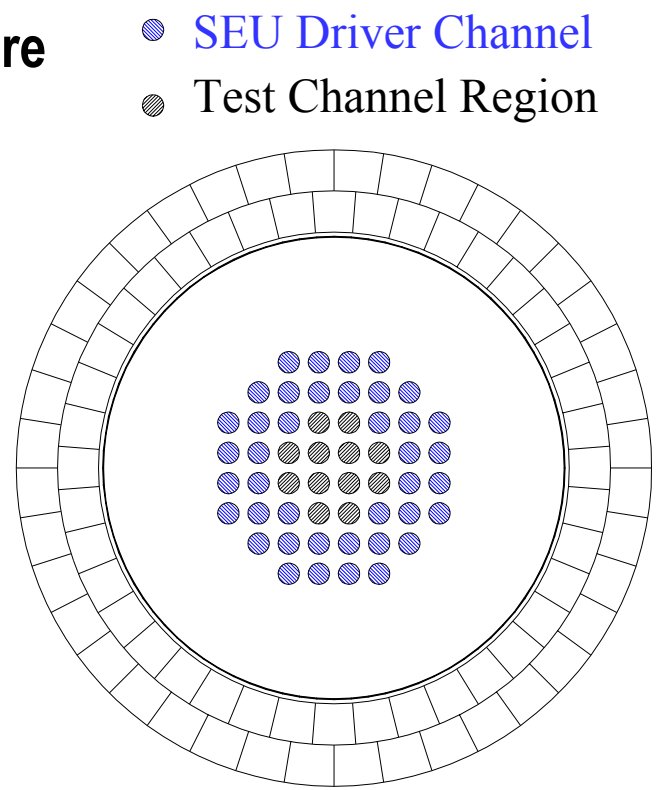
Buckling and Reactivity Coefficient Measurements

- Full-core flux maps using uniform hex CANFLEX SEU lattices
  - using existing (CANDU geometry) aluminum PT/CT assemblies
  - flux measurements into reflector
  - cooled and voided
- Moderator temperature reactivity
  - using uniform CANFLEX SEU hex lattice
  - 2 moderator temperatures
  - cooled and voided
- Moderator poison reactivity
  - measurements performed using uniform CANFLEX SEU hex lattice
  - 2 poisons (Gd and B)
  - 2 moderator temperatures
  - cooled and voided

(D.5.1)

Checkerboard Partial Void Measurements

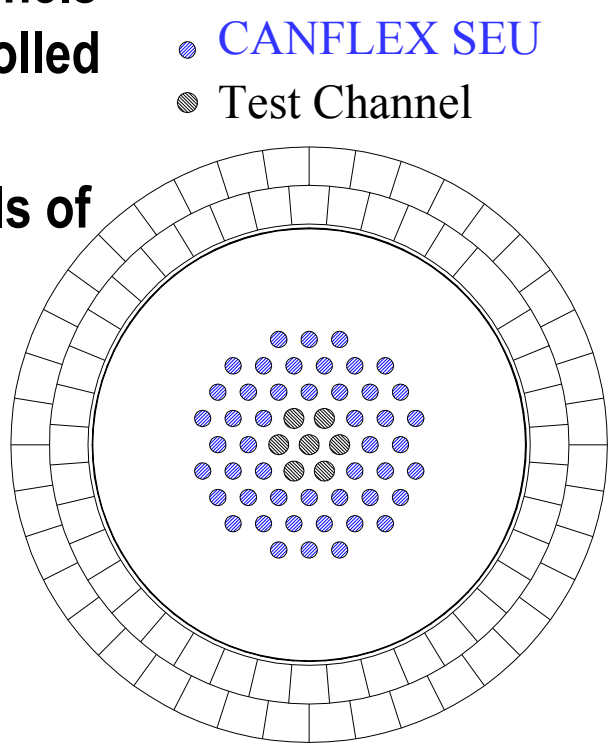
- Partial void experiments using a checkerboard void configuration in a square lattice
- 6 channels in a 12-channel test region will be modified to allow for the controlled variation of coolant density
- Measurements performed with
  - uniform CANFLEX SEU
  - 12 rods of CANFLEX LVRF
  - 12 rods of CANFLEX MOX
  - 6 rods of CANFLEX LVRF and 6 rods of CANFLEX MOX



(D.5.2)

Uniform Partial Void Measurements

- Partial void experiments using 7 test channels in a hex lattice modified to allow for controlled variation of coolant density
- Measurements performed using 7 channels of
  - CANFLEX SEU
  - CANFLEX LVRF
  - CANFLEX MOX

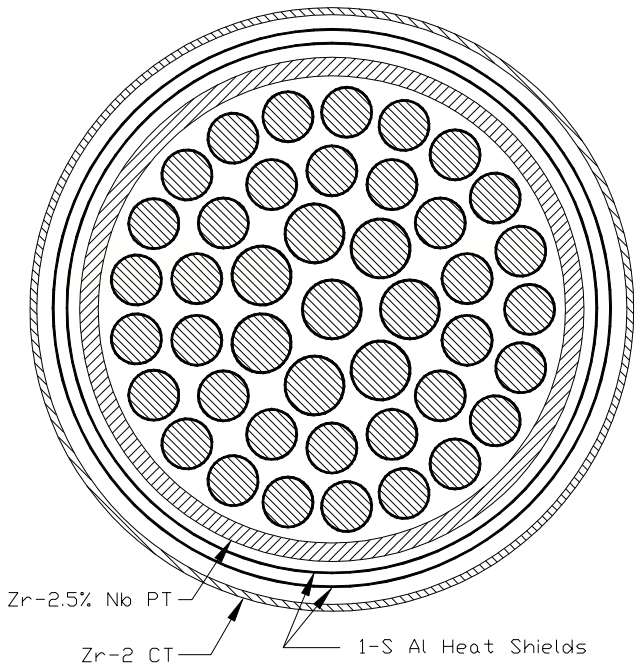


(D.5.3)

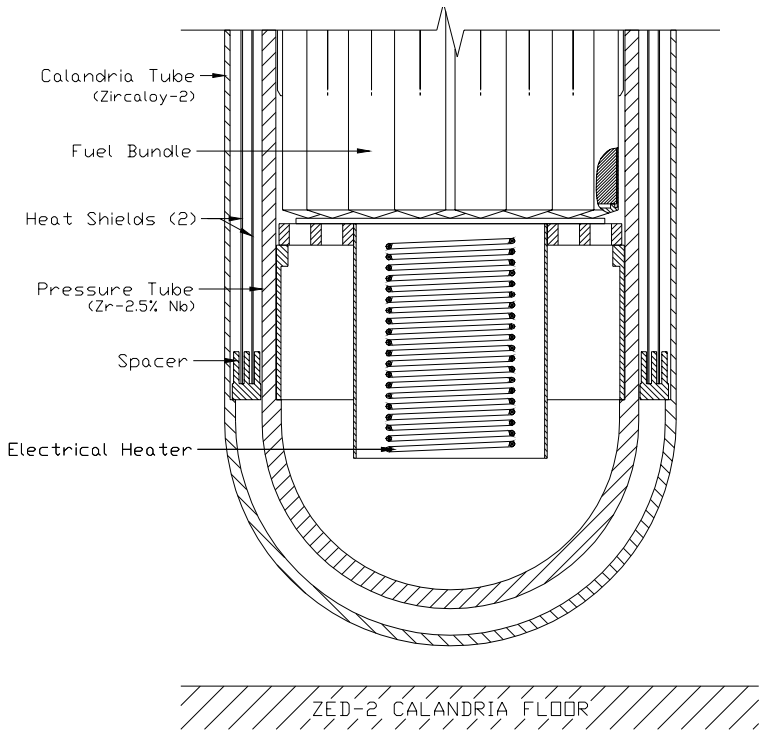
High temperature CVR and Fuel Temperature Reactivity

- **High-temperature CVR and fuel temperature coefficient measurements on CANFLEX LVRF and CANFLEX MOX in ZED-2 hot channels**

Hot Channel Plan View



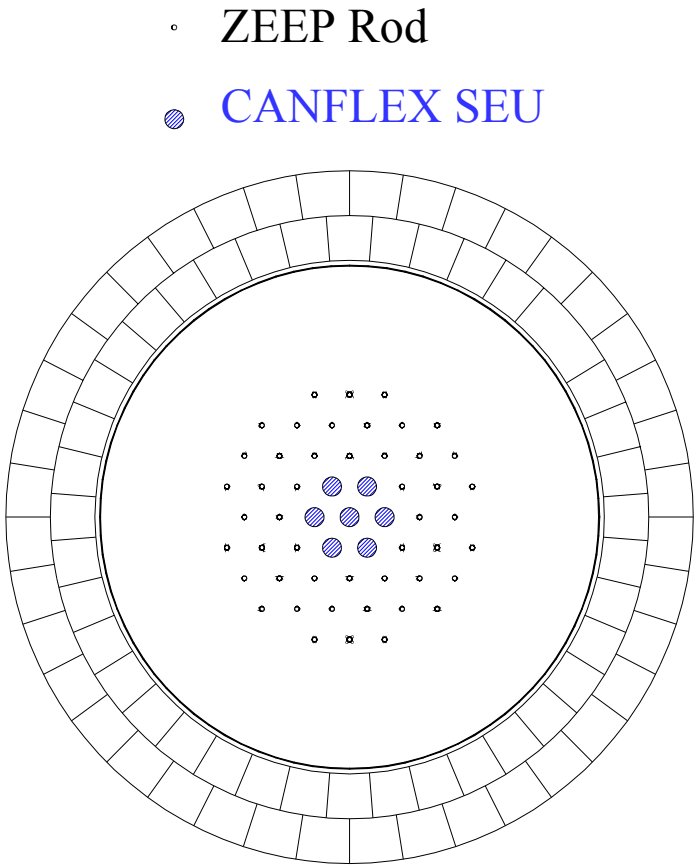
Hot Channel Bottom Section



(D.5.5)

Substitution of CANFLEX SEU into ZEEP Lattice

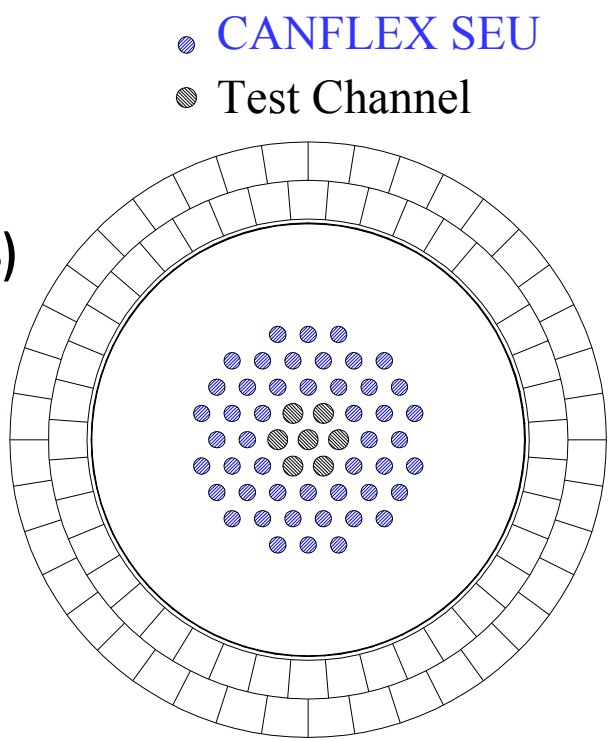
- **Substitution of 55 CANFLEX SEU bundles into hex ZEEP lattice**
  - **cooled and voided**
  - **will provide additional validation data for substitution method under ACR conditions**



(D.5.6 - D.5.9)

Other Substitution Measurements

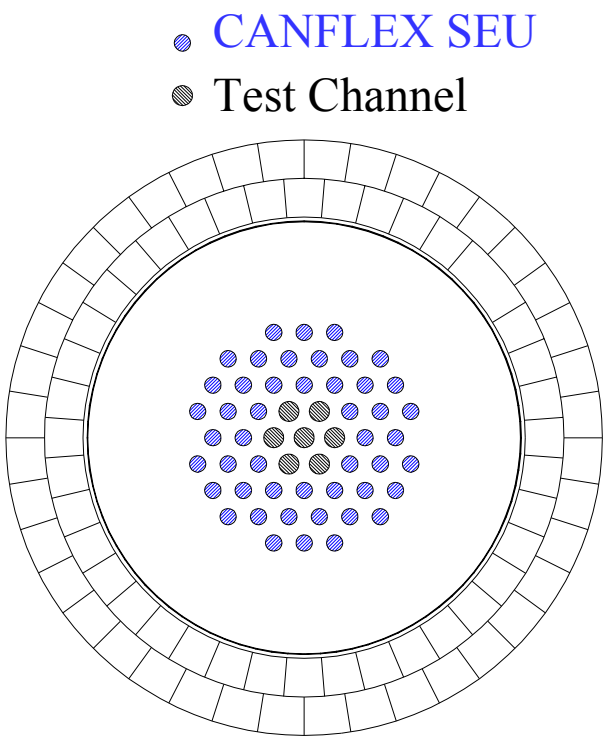
- Substitutions into CANFLEX SEU hex lattice
  - 37-element LVRF
  - CANFLEX LVRF (with ACR fuel channels)
  - 37-element MOX
  - CANFLEX MOX (with ACR fuel channels)
- Cooled and voided



(D.5.10)

Standard Fine Structure Measurements

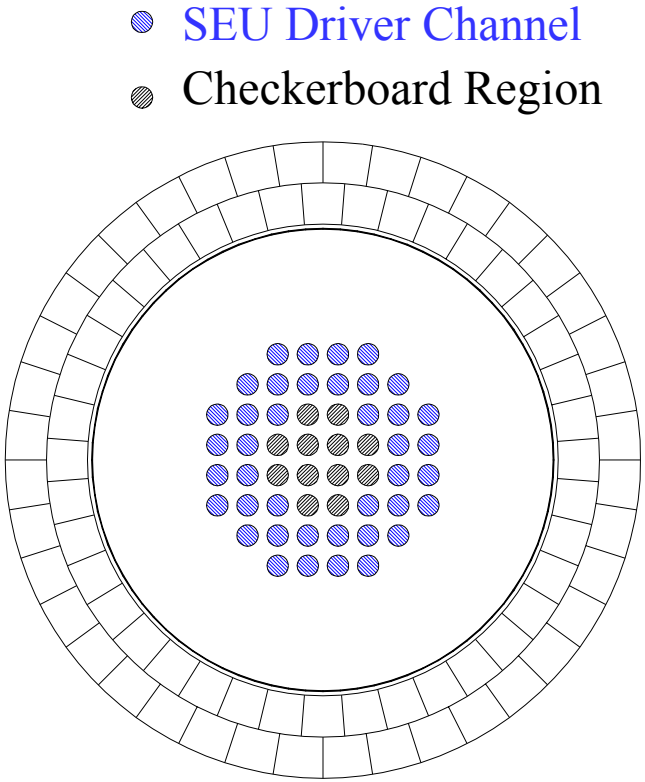
- 55-rod CANFLEX SEU hex lattice
- Central seven channels will be ACR-type and the central channel will contain a demountable bundle
- Measurements performed with central 7 test channels containing
  - CANFLEX MOX
  - CANFLEX LVRF
  - cooled and voided



(D5.11)

Fine Structure Measurements in Central Checkerboard

- Fine-structure reaction rates will be measured in a 52-rod square lattice with a 12-rod central checkerboard region comprising 6 rods of CANFLEX LVRF and 6 rods of CANFLEX MOX
- Central four channels will be ACR-type with 2 CANFLEX demountable bundles
  - 1 MOX
  - 1 LVRF



(D.5.11)

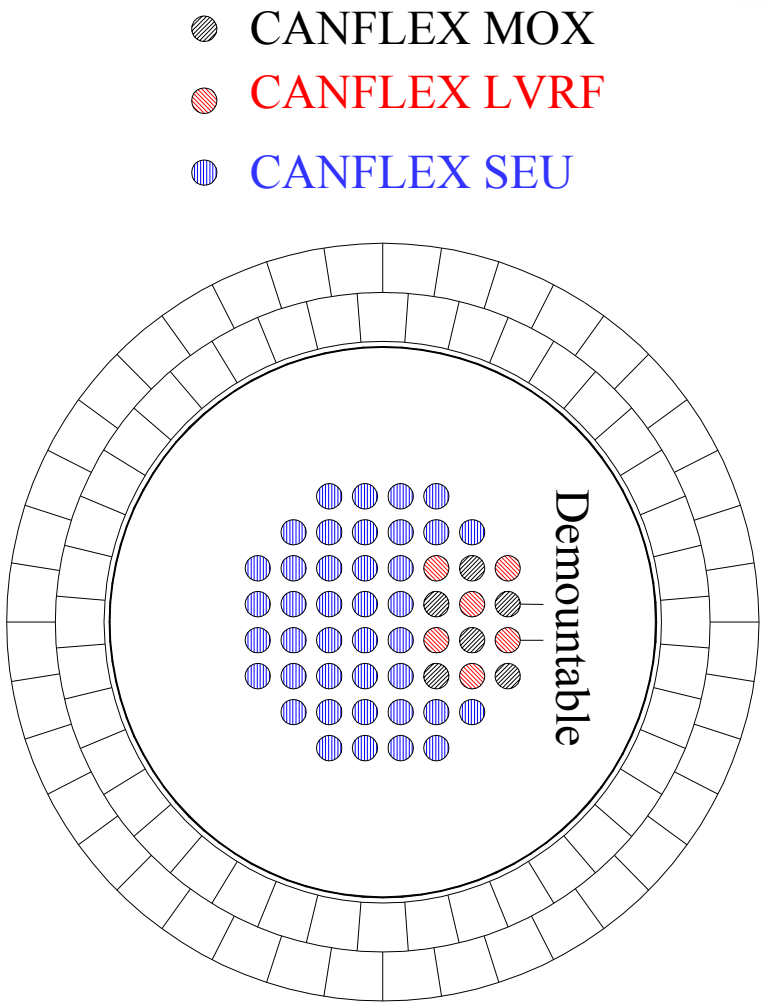
Fine Structure Measurements in Central Checkerboard (cont'd)

- Measurements include the following coolant conditions in the 12 test channels
  - all channels with H_2O coolant
  - all channels with air coolant
  - 6 MOX channels air cooled, 6 LVRF channels H_2O cooled
  - 6 MOX channels H_2O cooled, 6 LVRF channels air-cooled
- Above measurements will be repeated with absorbers suspended in the lattice
  - absorbers will include ACR-type
    - shut off rod
    - mechanical control absorber

(D.5.12)

Fine Structure Measurements at Core/Reflector Interface

- Fine-structure reaction rates will be measured in a 52-rod square lattice with a 12-channel checkerboard region located at the edge of the lattice
- Checkerboard region will comprise alternating channels of CANFLEX LVRF and CANFLEX MOX
- 2 demountable bundles will be positioned at the lattice-reflector interface (CANFLEX LVRF and MOX)



(D.5.13)

Fine Structure Measurements with H_2O-Filled Channel

- During refueling in ACR, fuel string moves downstream in channel, with 3 bundles left in core at furthest downstream location
  - ZED-2 square lattice of CANFLEX SEU, with central channel in empty (or with a single bundle)
  - fine structure measured in adjacent channels

(D.5.14)

End-flux Peaking

- 55-rod hex lattice with the 7-channel test region with CANFLEX LVRF in ACR-type channels and H_2O coolant; driven by 48 CANFLEX SEU channels
- Demountable CANFLEX LVRF bundle positioned in centre channel
- Detailed axial flux measurements using Cu foils between flat-ended pellets in the removable elements, as well as Cu wires positioned axially
- 2 measurements
  - 7 test channels each containing 5 CANFLEX LVRF bundles in each channel, with demountable bundle in centre of the fuel string
    - gives the end-flux peaking for the bundle-to-bundle configuration
  - centre channel containing only three CANFLEX LVRF bundles, the demountable bundle in the top position
    - gives end-flux peaking for the bundle-to-coolant configuration (encountered during refueling)

(D.5.15, D.5.16)

Kinetics Measurements and Device Worths

- Rod-drop experiment
  - measure the delayed photo-neutron component to Beta
- Reactor-period measurements
  - worths ACR-type shut-off rod determined using period measurements
  - shut-off rod suspended at various axial and radial locations in a square 52-rod uniform SEU lattice at a spacing representative of ACR
  - measurements repeated using mechanical control absorber
- Static measurements of control device worth

(D.5.17) Down-graded Moderator Experiments

- Flux maps with voided and H_2O-cooled CANFLEX SEU in uniform
  - square lattices
  - hexagonal lattices with down graded moderator

(D.5.18) Flux detector response measurements

- Will determine the following characterizations for an ACR-type lattice in ZED-2
  - measurement of effective neutron temperature
  - characterization/verification of the neutron energy spectrum
  - characterization of the neutron/gamma ratio at the proposed detector in-core locations
  - measurement of detector neutron (and gamma) sensitivity
  - determination of delayed/prompt detector signal components
  - determination of gamma detector signal components

Summary

- Report on suitability of ZED-2 for ACR physics validation
- More extensive analysis than in the past, with additional analysis approaches
  - integral WIMS/DRAGON/RFSP, and MCNP validation
- Experimental components
  - checkerboard voiding measurements
  - reactivity coefficients including CVR, fuel temperature, and partial void reactivity
  - fine-structure measurements
  - reactivity device measurements
  - kinetics measurements

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E: ACR Physics Toolset Validation

Hank Chow
Senior Physicist, Reactor Core Physics Branch, AECL

Presentation to US Nuclear Regulatory Commission
Rockville, MD
December 02, 2004

AECL TECHNOLOGIES INC.

Plan Outline

E.1 WIMS validation against existing ZED-2 measurements (existing fuel under ACR conditions)

E.2 WIMS/DRAGON/RFSP validation against new ZED-2 measurements (using CANFLEX SEU reference fuel)

E.3 WIMS/DRAGON/RFSP validation against data from other critical facilities

E.4 MCNP validation against ZED-2 and other measurements

E.5 WIMS/DRAGON/RFSP benchmarking against MCNP

E.6 Validation of Dy modeling

E.1 WIMS Validation Against Existing ZED-2 Measurements

- Measurements have been completed with existing fuel and ACR-like lattice conditions
  - 28-element NU fuel full-core flux map
  - 37-element LVRF, SEU fuel, Dy-doped elements, substitution
  - 43-element LVRF, 1% enrichment, 15% Dy/NU central element, substitution at room temperature and 300°C, fine-structure measurements
- Data used in validation of WIMS developmental version
- Will repeat validation using WIMS 3.0

E.2 WIMS/DRAGON/RFSP Validation Against New ZED-2 Measurements

- New measurements using reference lattice with CANFLEX SEU fuel (0.95% U-235)
- Validation approach has been expanded
  - WIMS validation using measured buckling and reaction rates
  - WIMS/DRAGON/RFSP validation by full-core modeling of ZED-2
- Validation reports will be written as new experiments are completed, analyzed and used for validation
- Reactor physics toolset validation manual will be updated periodically

E.3 WIMS/DRAGON/RFSP Validation Against Data from Other Critical Facilities

- A collection of reports and papers on DCA, DIMPLE, ECO and Savannah River gathered and under review
- Selected data sets to be included in validation matrix
- Analysis done in near-term period

E.4 MCNP Validation

- Accuracy of MCNP will be established, using ZED-2 measurement data, and data from other critical facilities
- Work planned according to the same 2 time periods as experiments
- Selected experiments will be modeled using MCNP
- MCNP will be used to benchmark standard physics toolset
  - for extrapolating from MCNP to ACR-700 conditions

E.5 WIMS/DRAGON/RFSP Benchmarking Against MCNP

- MCNP will be used to extend validation database beyond ZED-2, to ACR-700 conditions
  - MCNP is fundamentally rigorous code
  - nuclear data is the main uncertainty
  - will address ACR conditions, e.g. operating temperatures, crept pressure tube, non-concentric PT and fuel bundle, and postulated accident conditions
- Single lattice-cell calculations – WIMS vs. MCNP
  - coolant void reactivity
  - temperature reactivity coefficients
  - moderator purity, poison reactivity coefficients
- Full-core calculations – WIMS/DRAGON/RFSP vs. MCNP
  - full core flux and power distribution with various device configurations
  - full-core void and checkerboard void reactivity
  - device reactivity worth
  - reaction rates in fine-structure measurements

E.6 Validation of Dy Modeling

- WIMS will be validated with regard to Dy modeling and Dy depletion calculations using data from NRU irradiation of Dy-doped fuel bundles
  - impact of Dy modeling accuracy on CVR predictions will also to be assessed
  - NRU and power reactor measurements will also be used to validate codes for isotopic evolution

Summary

- Validation will include both WIMS/DRAGON/RFSP toolset, and MCNP
- Validation plan schedule will follow the 2 time-periods of ZED-2 experimental program
- Validation database will include suitable data from other critical facilities
- Benchmarking of WIMS/DRAGON/RFSP against MCNP is an essential component of validation program

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Path Forward: Pre-Application Phase 3

Glenn H. Archinoff
Manager, ACR Licensing, AECLT

Presentation to US Nuclear Regulatory Commission

Rockville, MD

December 02, 2004

AECL TECHNOLOGIES INC.

Background

- **Pre-application meetings to date:**
  - December 4-5, 2002
  - April 19-23, 2004 (workshop on physics codes)
  - July 27-29, 2004
- **Pre-application RAIs 1-14 (May 13, 2003):**
  - RAIs 1-11 – responses sent on June 15, 2003*
  - RAI 12 – responses sent July 22 and July 25, 2003
  - RAI 13 – response sent October 22, 2004
  - RAI 14 – responses sent November 13, 2003

* Responses to RAIs 1 and 4 may need to be updated upon any change in the ACR-700 fuel design

Pre-Application Documentation Submissions in Support of ACR-700 Physics

- WIMS-AECL Theory Manual (10-Dec-02)
- System Validation Manual for WIMS-IST/DRAGON-IST/RFSP-IST Reactor Physics Code Suite (10-Dec-02)
- WIMS-AECL Release 2-5d Users Manual (10-Dec-02)
- DRAGON Theory Manual - Part 1: Collision Probability Calculations (10-Dec-02)
- Development of Simple-Cell Model for Performing History-Based RFSP Simulations with WIMS-AECL (10-Dec-02)
- A Phenomenon-Based Matrix of Texts for Use in Validation of Reactor Physics Codes Employed in Nuclear Safety Analysis (10-Dec-02)
- RFSP-IST User's Manual (10-Dec-02)
- RFSP-IST Theory Manual (10-Dec-02)

Pre-Application Documentation Submissions in Support of ACR-700 Physics (cont'd)

- ACR-700 Reactor Physics Design, 10810-03300-ASD-001(15-Jun-03)
- WIMS-AECL Rel 2-5d, RFSP-IST Ver 3-03, DRAGON-IST Reports (25-Jul-03)
- Summary of Verification Tests for WIMS-IST (12-Aug-03)
- A Phenomenon-based Matrix of tests for Use in Validation of Reactor Physics Codes Employed in Nuclear Safety Analysis (17-Oct-03)
- ACR Physics Experiments in ZED-2 using NU Fuel (13-Nov-03)
- Planned Physics Experiments in ZED-2 in Support of ACR (13-Nov-03)
- Analysis of Full-Core and Substitution Experiments with 28-Element UO2 Fuel at 20-22.86 cm Pitch (13-Nov-03)
- Substitution Experiments on 37-Element LVRF Fuel into a 21.59-cm Pitch ZED-2 Lattice (13-Nov-03)

Pre-Application Documentation Submissions in Support of ACR-700 Physics (cont'd)

- Fine-Structure Measurements on 37-Element LVRF in a 21.59-cm Pitch ZED-2 Lattice (13-Nov-03)
- Analysis of Substitution Experiments on 37-Element LVRF Fuel into a 21.59-cm Pitch ZED-2 Lattice (13-Nov-03)
- Validation of WIMS-AECL on Tight Pitch ZED-2 Experiments using Light Water Cooled 28-Element NU Fuel (13-Nov-03)
- MCNP Checkerboard Voiding Calculation (22-Oct-04)
- Sensitivity of ACR-700 Full-Core Void Reactivity and Power Distribution to the Number of Neutron Energy Groups (22-Oct-04)

Path Forward: Pre-Application Phase 3

- Additional documents to be provided to NRC
  - description of code development and experimental program (Jan. 31, 2005)
  - coupled multi-channel thermal hydraulics and reactor physics large break LOCA simulation (Feb. 15, 2005)
  - report on suitability of ZED-2 for ACR-700 experiments
- Sufficient information to facilitate NRC simulations of ZED-2 experiments
  - discuss NRC requirements
- PASAR follow-up
  - actions being assigned to address all issues/concerns identified in PASAR
  - will address via meeting discussions, document submittals as necessary
  - objective to address as many issues as possible before DCD submittal
- Meetings
  - suggest quarterly progress update meetings throughout 2005

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