Physics Tool-Set Qualification Plan for ACR Applications

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Introduction

– Detailed qualification plan being developed
– Major component at this stage is ZED-2 measurements

Presentation Outline

– **Code validation methodology**
– **PHs and relevance to ACR**
– **Code qualification plan / process**
  - ZED-2 measurements
  - Existing data from other facilities with ACR-type lattices
  - Inter-code comparisons
  - Dy-doped fuel measurements and irradiation data
  - Power reactor measurements
– **Summary**

IST Codes Validation Methodology

- Technical Basis Document
  - Safety concerns, accident scenarios vs governing phenomena
  - PKPIRT (Phenomena Key Parameters Importance Rank Table)
  - To be revised to cover ACR
- Validation Matrix
  - PH vs Accidents, also relative importance of PH
  - PH vs Measurement Data
  - To be revised to cover ACR
- Validation Plan
- Validation Tasks
- Validation Report

Physics Phenomena and Codes Capturing the Phenomena

PH No.	Reactor Physics Phenomenon	Primary Code(s)
PH1	Coolant-Density-Change Induced Reactivity	WIMS-AECL
PH2	Coolant-Temperature-Change Induced Reactivity	WIMS-AECL
PH3	Moderator-Density-Change Induced Reactivity	WIMS-AECL
PH4	Moderator-Temperature-Change Induced Reactivity	WIMS-AECL
PH5	Moderator-Poison-Concentration-Change Induced Reactivity	WIMS-AECL
PH6	Moderator-Purity-Change Induced Reactivity	WIMS-AECL
PH7	Fuel-Temperature-Change Induced Reactivity	WIMS-AECL
PH8	Fuel-Isotopic-Composition -Change Induced Reactivity	WIMS-AECL/RFSP-IST
PH9	Refuelling-Induced Reactivity	RFSP-IST
PH10	Fuel-String-Relocation Induced Reactivity	RFSP-IST
PH11	Device-Movement Induced Reactivity	DRAGON/RFSP-IST
PH12	Prompt/Delayed Neutron Kinetics	RFSP-IST
PH13	Flux-Detector Response	RFSP-IST
PH14	Flux and Power Distribution in Space and Time	WIMS-AECL/RFSP-IST
PH15	Lattice-Geometry-Distortion Reactivity Effects	WIMS-AECL/RFSP-IST
PH16	Coolant-Purity-Change Induced Reactivity	WIMS-AECL

Physics Phenomena and Accident Scenarios

	Initial Conditions	Basic Accident Scenarios							
		Large LOCA	Small LOCA	LOCA + failure of ECC	Secondary Coolant Failures	Fuel Handling Accidents	LOR	LOF	Auxiliary System Failures
PH1		major	minor	major	minor	minor	major	major	
PH2		minor	minor	minor					minor
PH3			minor						major
PH4			major						minor
PH5		minor	major	minor					
PH6			major						
PH7		minor	minor	minor					minor
PH8		minor	minor	minor	minor	minor			minor
PH11		major	major	major	minor	major	major	major	major
PH12			major	minor	major		minor	minor	major
PH13	major	minor	minor	minor	minor	minor	minor	minor	major
PH14	major	major	major	major	minor	major	major	major	major
PH15		minor	minor	minor					
PH16		minor	minor	minor					

* The entries in this Table are for current CANDU reactors, will be revised for ACR

PH Validation Considerations

- **Separation of PHs**
  - Simultaneous occurrence of PHs inherently related (temperature and density)
  - Simultaneous occurrence in experimental set-up or accident transients (coolant and fuel temperature changes)
  - A few PHs likely to occur at the same phase of an accident event
- **Goal: Quantify Biases and Uncertainties for each PH**
  - Established for a frozen code version and data library
  - Input data used to model the real physical situation
  - Inaccuracies in basic nuclear data
  - Code numeric, and approximations in solution method and model
  - Within the bounds of measurement accuracy

ZED-2 Measurement Planned

	Experiment	Purpose	Phenomena
1	Criticality and coolant void reactivity **flux maps**	Lattice and void reactivity for SEU fuel in H_2O and air cooled tight lattices	PH1
2	Criticality and coolant void reactivity **substitutions**	Lattice and void reactivity for SEU fuel in H_2O and air cooled tight lattices with **expanded calandria tubes**	PH1
3	Fuel/coolant temperature coefficient	**Temperature reactivity coefficients (up to 300^0) for both SEU and MOX** fuel in H_2O and air cooled tight lattices	PH1 / PH2 / PH7
4	Moderator temperature coefficient by flux map measurements	**Moderator temperature coefficient in the range 10^0 to 40^0 C for SEU** fuel in H_2O and air cooled tight lattices	PH1 / PH3 / PH4
5	Fine structure flux distribution	**Flux distribution** in a SEU CANFLEX bundle at both room in **H_2O and air cooled** tight lattices	PH1 / PH2 PH7 / PH14
6	Moderator poison experiments	**Boron and/or Gd reactivity effect** in ACR type lattices using both H_2O and air coolant	PH1 / PH5
7	Benchmark configuration flux distribution	Spatial flux distribution in **a heterogeneous ACR-type lattice** of SEU 43-element CANFLEX and MOX 37-element bundles	PH8 / PH14
8	Control device measurements	**Absorber device** inserted into square uniform or checkerboard lattice of **SEU 43-element CANFLEX and MOX 37-element bundles**	PH11
9	Rod drop experiments	Assessment of the contribution of **delayed photo-neutrons** to the delayed fraction	PH12

Coverage of PH / Code Predictions by ZED-2 Measurements

- WIMS-AECL in the estimation of coolant-void reactivity (fresh and irradiated fuel)
- WIMS-AECL in the estimation of combined coolant- and fuel-temperature reactivity (fresh and irradiated fuel)
- WIMS-AECL in the estimation of combined moderator-temperature and -density reactivity, cooled and voided lattice (fresh fuel)
- WIMS-AECL in the estimation of fine flux in cooled and voided lattices (fresh fuel)
- WIMS-AECL estimation of moderator-poison reactivity for cooled and voided lattices (fresh fuel)
- WIMS-AECL/RFSP-IST estimation of ZED-2 global flux shape with heterogeneous fuel burnup
- DRAGON-IST modeling of the absorber device
- Contributions from the delayed photo-neutrons to the total delayed fraction

Relevant Data from Deuterium Critical Assembly - FUGEN Project, Japan

Square lattice pitch:	**20.0, 22.5, 25.0 cm**
Fuel enrichment:	**0.71, 1.2, 1.5% enriched UO_2**
	0.54, 0.87% PuO_2
Coolant:	**H_2O; mixture of H_2O and D_2O; D_2O; Air**
Void fraction:	**0, 30, 70, 86.7, 100 %**
Poison:	**0 – 10 ppm ^{10}B**
Fuel bundle:	**28-element cluster**
Fuel pellet:	**R=0.74 cm, 10.33 g/cm^3**
Fuel/Clad Gap:	**R=0.7515 cm, He**
Cladding:	**R=0.8365 cm, Al**

DCA Measurements

- Critical moderator level
- Material buckling
- Migration area
- Neutron flux distribution
- Power distribution
- Moderator level coefficient of reactivity
- Coolant void coefficient of reactivity
- Coolant temperature reactivity
- Control rod reactivity
- Boron worth
- Kinetic parameters

Relevant Data from Other heavy-water moderated and light-water cooled facilities

- ECO, CIRENE Project, Italy
- Savannah River Laboratory
- DIMPLE, SGHWR, Winfrith, UK

Inter-Code Comparisons at Lattice-Cell Level - MCNP vs WIMS

- An integral component of the validation program - complementary to comparisons to measurement data
- Cover the ranges of parameters overlapping with available measurement data - verify how MCNP performs vs measurements
- Extend to cover power reactor conditions and postulated accident conditions where no measurement data exist
- Can include cross-PH effects

Validation of PHs by Measurements from ZED-2, DCA, ECO, and inter-code comparisons to MCNP

Phenomenon	SEU fuel ZED-2 measurements+	Existing data	Code-to-code validation
PH01	1, 2, 3, 4	DCA, ECO	MCNP4C
PH02	3	DCA	MCNP4C
PH03, PH04	4	DCA	MCNP4C
PH05	6	DCA	MCNP4C
PH06			MCNP4C
PH07	3	DCA	MCNP4C
PH08	7	DCA, ECO	MCNP4C*
PH09			
PH10			
PH11	8		MCNP4C*
PH12	9		
PH13			
PH14	5, 7	DCA, ECO	MCNP4C*
PH15			MCNP4C*
PH16			

+ Numbers here correspond to those in Table on Page 7

* Partial coverage of PH, additional coverage provided from RFSP validation

Dy Modeling and Dy burnout

- **Modeling of Dy burnout via WIMS burnup calculations (Part of PH08 Fuel Composition Change Induced Reactivity)**
- **Existing Validation Data – Fresh Fuel**
  - 37-element bundle
  - 1.35% enrichment in outer ring, 1.92% in middle ring
  - Depleted U (0.35% U-235) with 2% Dy in inner ring, depleted U with 10% Dy in central element
  - 7-rod substitution measurements of buckling, cooled and voided, temperature range from 25^{o}C to 300^{o}C
  - Fine structure measurements at room temperature for both cooled and voided cell
  - WIMS-AECL void prediction accuracy: 0 mk bias ± 1 mk uncertainty

Dy Modeling and Dy burnout (Con't)

- **Existing data for Dy depletion**
  - PIE of fuel elements with Dy irradiated in NRU (La content, Dy content and fractions of Dy isotopes)
  - Two 36-element bundles (central-rod stringer) same fuel composition as above
  - A third demountable bundle with outer elements poisoned by up to 15% Dy
  - Database for quantitative judgment of the accuracy of WIMS modeling of Dy burnout calculations (in progress)

Validation of WIMS/DRAGON/RFSP Full Core Calculations - Measurements from Power Reactor

- **Moderator poison reactivity effect**
  - PH5, also covered by ZED-2 measurements
- **Device-worth measurements**
  - PH11, also covered by ZED-2 measurements
- **Heat Transport (coolant and fuel) temperature reactivity effect**
  - PH2/7, also covered by ZED-2 measurements
- **Moderator temperature reactivity effect**
  - PH3/4, also covered by ZED-2 measurements
- **Flux shape measurements of nominal and off-nominal core states** (PH14)
- **Detector responses in perturbed core states** (PH13/14)
- **Flux measurements in a shutdown transient** (PH5/8)
- **Zone response immediately after fuelling and subsequent fission products build-up transient** (PH8/9)

Validation of WIMS/DRAGON/RFSP Full Core Calculations – Test Facility Measurements and Inter-Code Comparisons

- **ZED-2 Measurements (DCA Measurements)**
  - Full core modeling of ZED-2 by RFSP
  - Lattice properties of background lattice and test fuel bundles generated by WIMS
  - Measured critical moderator height used in the model
  - δk of the “before” and “after” core state represents code-error in simulation of the perturbation
- **MCNP vs RFSP**
  - 2-D axial plane model: comparison of radial flux shape changes upon coolant voiding
  - 3-D partial core model of 3 x 3 array of channels: comparison of axial leakage effect
  - 3-D full core model

Validation Exercises and Overall Validation Report

- **Validation Tasks**
  - Each measurement data set will be compared to calculations with the appropriate code(s)
  - Inter-code comparisons cover the ranges of parameters overlapping with available measurement data, and with extrapolations to accident conditions
  - Multi validation tasks for each PH
  - Detailed scope and specifications to be established
- **Overall Validation Report**
  - Results from all validation tasks related to each PH are summarized and integrated to establish code bias and uncertainty in modeling of the PH