Status and Requirements of GEN-IV Reactor Physics Studies in Korea

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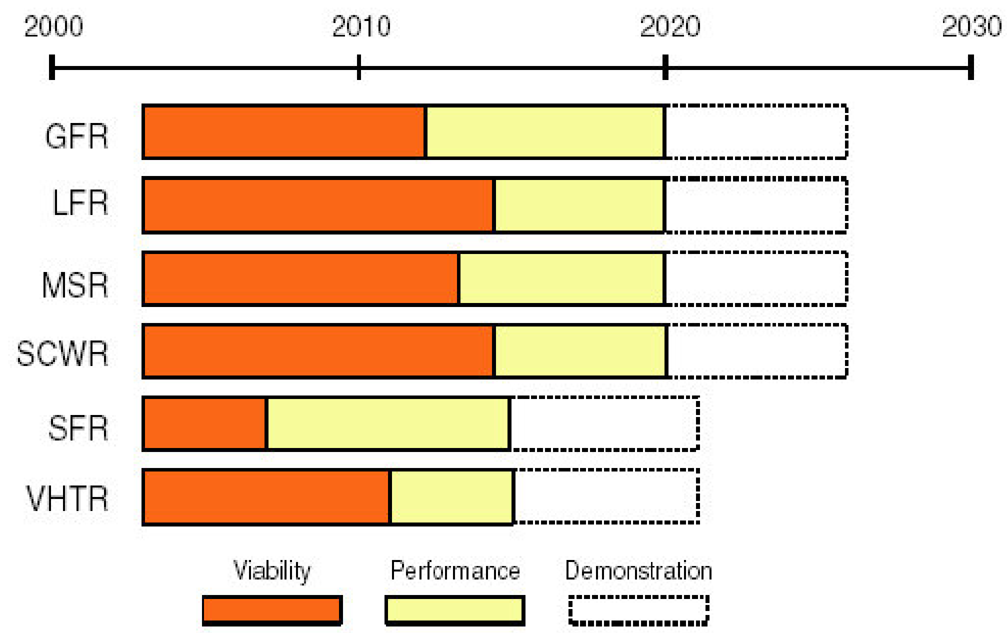
Prologue

- Once at a ANS conference, someone uttered a joke,
  "When the States cough, Korea catches cold."

- GEN IV reactor types of current Korean interest.
  - VHTR
  - SFR
  - SCWR



System development timelines

Outline

- ☐ **Reactor Physics Study Activities in Korea by Three GEN-IV Reactors**
  - VHTR
  - SFR
  - SCWR
- ☐ **High Fidelity Core Analysis Code Development**
  - 3-D Whole-Core Transport Code
  - Monte Carlo Code with Depletion and Thermal Feedback Capabilities
- ☐ **Wrap-up**

VHTR Physics Study Activities

□ VHTR Project Goals

- **Construct a demonstration VHTR for hydrogen production by 2016-19 .**
- **Develop coated fuel particle manufacturing technology.**
- **Decide target reactor type by 2006 (either pebble bed or prismatic)**

VHTR Physics Study Activities

☐ Current Status of Research Activities

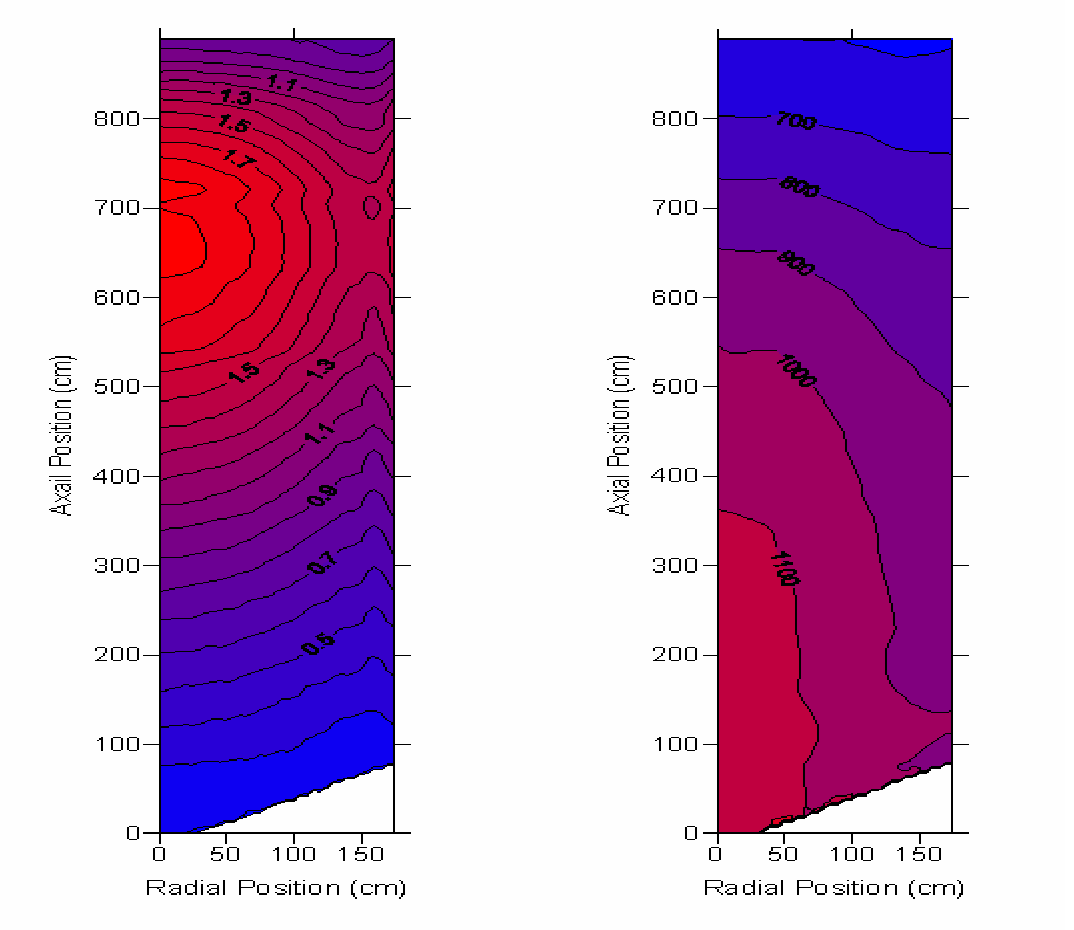
- ➢ **Constructed Web site for VHTR Database**
  - www.hydrogen.re.kr
  - Rich compilation of papers, reports, and presentation materials related with hydrogen production and VHTR analysis
- ➢ **Installed and Examined the VSOP94 Code System**
  - 1-D GAMM/THERMOS, 2-D CITATION, FEVER, THERMIX, etc
  - Used it for Analysis of PROTEUS Experiment
  - Adopted it for Pre-conceptual Designs
- ➢ **Performed Pebble Flow Experiment by using a Test Miniature**
- ➢ **Carried out Pre-conceptual Design of Pebble Bed and Prismatic Reactors**
  - 150 Mw(th) and 300 Mw(th) Pebble Bed Reactors
  - 600 Mw(th) Prismatic Reactor

Pre-conceptual Design: 300MWth Pebble Bed Reactor

Specification

Design Parameter	Value
Equivalent Core Diameter (cm)	350
Equivalent Core Height (cm)	890
Inlet/outlet Helium Temperature (℃)	500/ 1,000
Number of Pebbles in the Core	433,300
Number of Passes to the Core	10
Average Residence Time of Fuel Element (day)	1,200
Average Discharge Burnup (MWD/T)	114,200

Power / Fuel Temp.



VHTR Physics Study Activities

☐ Outstanding Issues

- ➢ **VHTR Specific Cross Section Library**
  - Graphite Scattering Matrix
  - Resonance Data at High Temperatures
- ➢ **2-D Lattice Transport and Depletion Code**
  - Double Heterogeneity Arising from Adoption of Coated Fuel Particles
- ➢ **Nodal Codes for Prismatic Cores**
  - Neutron Streaming in Gas Coolant Channels
  - Fuel/Reflector Coupling – New Homogenization
- ➢ **Nodal Codes for Pebble Bed Cores**
  - r-z-θ Nodal Method to Tackle Azimuthally Non-symmetric Arrangement of Peripheral Control Rods
  - Pebble Flow and Depletion

VHTR Physics Study Activities

☐ Plans and Strategies to Resolve Issues

- **Generation of VHTR Specific Library**
  - Generate WIMSD4 Cross Section Library
- **Establishment of Pebble Bed Core Analysis System**
  - Develop AFEN Based r-z-θ Nodal Method
  - Incorporate Pebble Flow Modeling
- **I-NERI Collaboration to Develop Advanced Deterministic Code System for Prismatic Cores**
  - Establish Group Constant Generation System by Making Use of Existing Lattice Physics Codes Capable of Handling Double Heterogeneity (e.g. DRAGON)
  - Utilize Multigroup Hexagonal Handling Feature of MASTER by Incorporating Direction Dependent Diffusion Coefficients (Neutron Streaming) and Developing Equivalence Theory Parameters for Fuel/Reflector Coupling

VHTR Physics Study Activities

□ Plans and Strategies to Resolve Issues

- ➢ **I-NERI or International Research Collaboration Aiming at Advanced Deterministic Code System for Prismatic Cores**
  - Extend the DeCART Whole Core Calculation Capability to Hexagonal Geometry and Double Heterogeneity Treatment.
  - Verify and Validate the DeCART Capability through Analysis of Benchmark Experiments and/or Comparison with Monte Carlo Simulations

SFR Physics Study Activities

❑ SFR Goals

❖ Extension of about-10-year-old KAERI KALIMER-150 project

- Develop basic key technologies for liquid metal reactors that can meet the goals of sustainability, safety and economic competitiveness
- Establish computational tools and sodium technology.

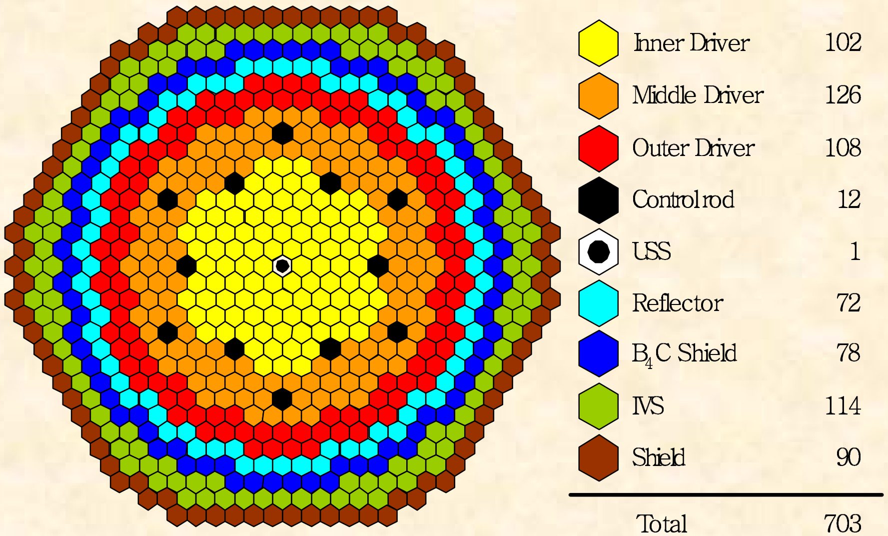
❑ Status

- KALIMER-600 design is underway.

SFR Physics Study Activities

☐ KALIMER-600 Design Concept

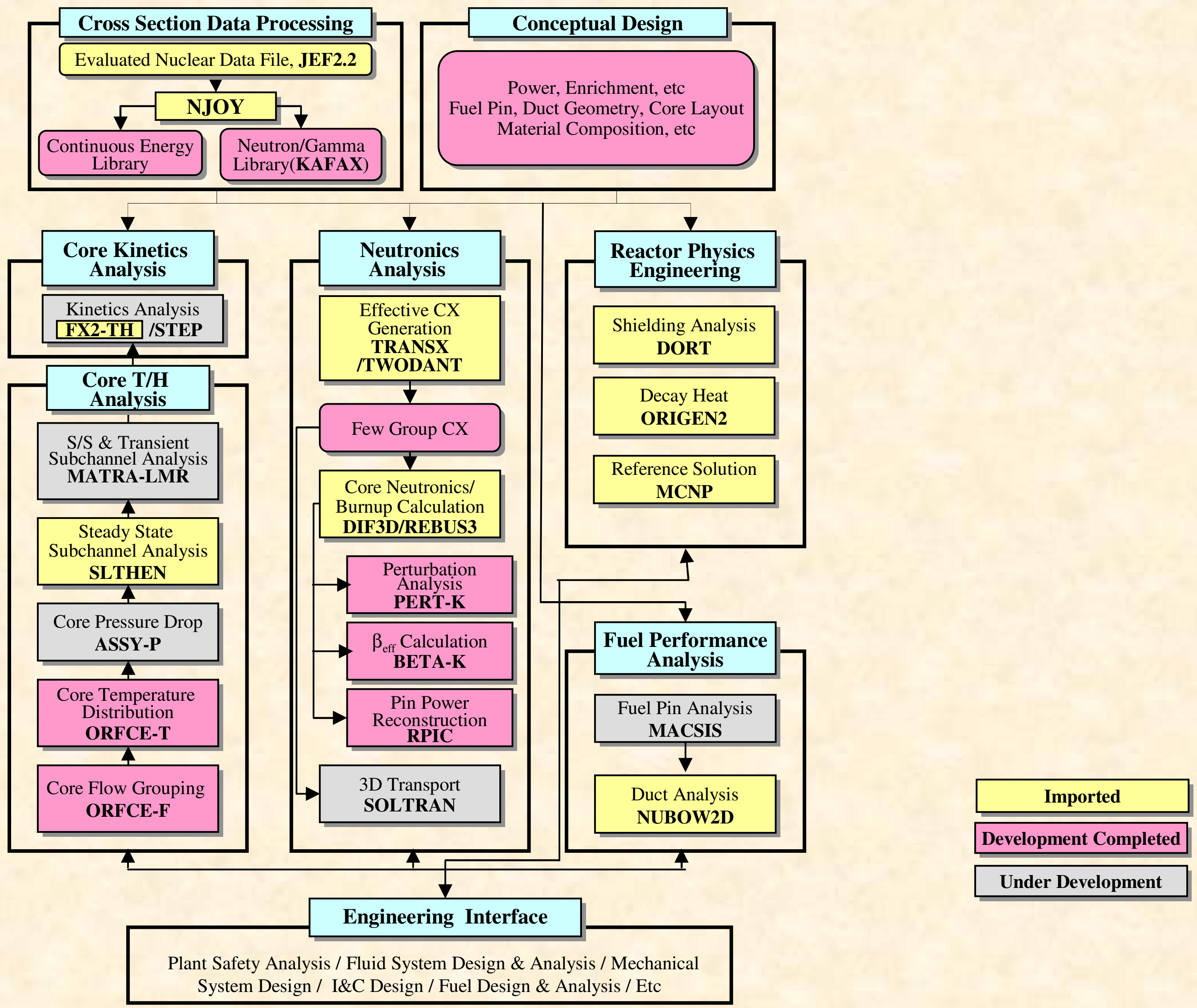
- Metal fuels loaded in sodium-cooled reactor core
- Self-recycling of transuranics with minimum excess Pu produced
- Proliferation resistance by removing blanket assemblies
- Design optimization to reduce sodium void effect: 4 ZrH2 moderator rods/FA



Average Breeding Ratio	1.004
Refueling Interval (month)	18
Average TRU in Heavy Metal (%)	16.1
Burnup Reactivity Swing (pcm)	2.0
Average Core Power Density (W/cc)	193
Average Discharge Burnup (MWD/kg)	66.6
Peak Fuel Discharge Burnup (MWD/kg)	97.4
Peak Discharge Fast Fluence (10^{23} n/cm^2)	2.90
Sodium Void Effect (pcm)	1,992
Fuel Doppler Coefficient ($d\rho/dT$)	$-0.0051T^{-0.9}$
Axial Expansion Coefficient (pcm/%)	-198
Radial Expansion Coefficient (pcm/%)	-424
β_{eff}	0.00361

SFR Physics Study Activities

☐ SFR Analysis Procedure



SFR Physics Study Activities

☐ Outstanding Issues of Kalimer-600 Reactor Physics Studies

- **Confirmation of breeding ratio and self-sufficiency of Pu production**
  - Very small margin in breeding ratio (currently, 0.004)
  - Target Amount of just self-sufficient Pu production, which will not require external feed of Pu.

- **Prediction of Intra-assembly power distribution**
  - Excessive power peaking around ZrH_2 moderator rods

- **Core neutronics**
  - Axial & radial neutron streaming in the control rod follower
  - Radial neutron distribution in the rodded cases

- **Verification and validation of computer tools in use**
  - Integral experiments and operation data
  - TRU cross sections

SCWR Physics Study Activities

☐ SCWR Goals

❖ Started in 2003 as a KAERI-funded research project

- Develop a conceptual design of a SCWR core
- Establish computational tools for SCWR analysis

SCWR Physics Activities

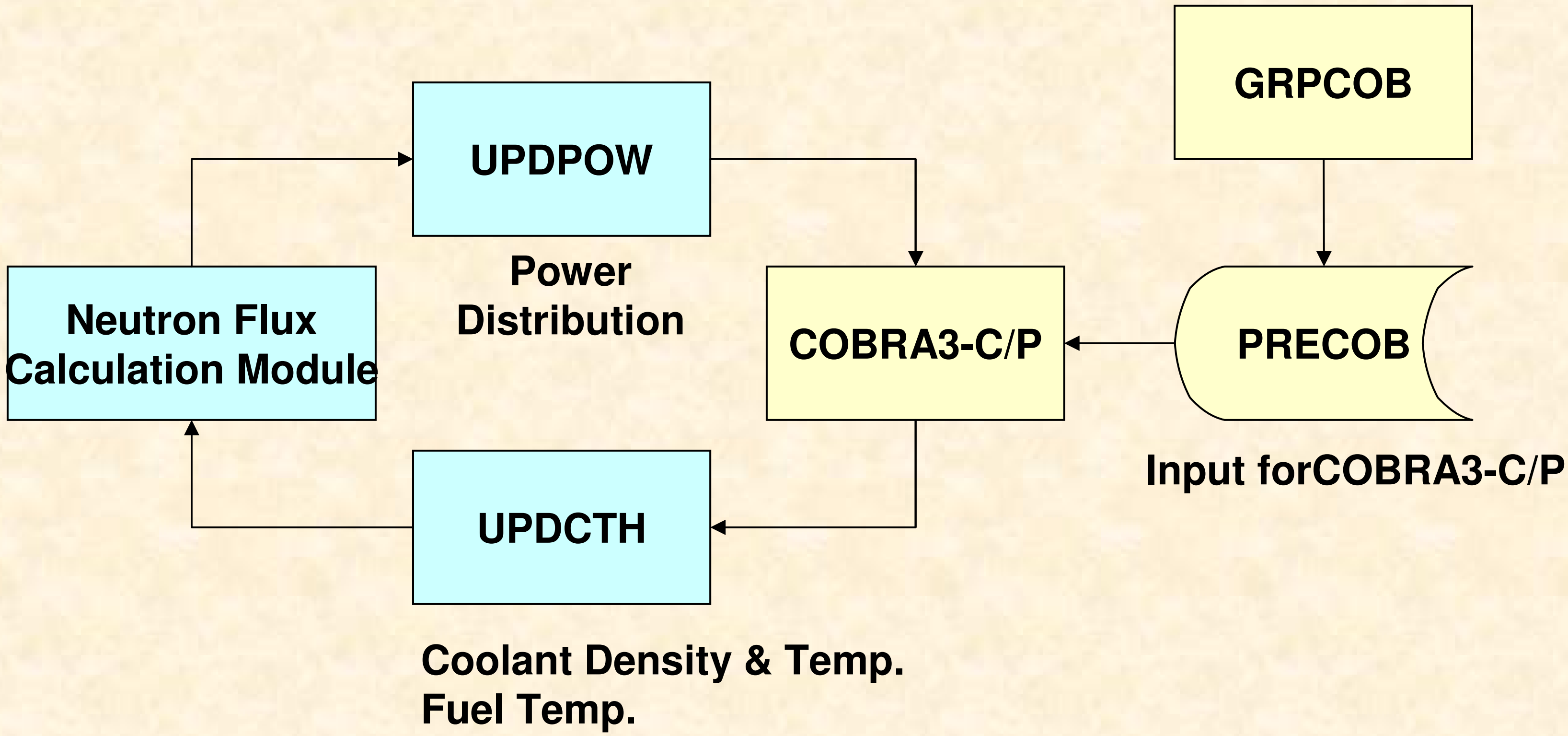
□ Current Status of Research Activities

- ➢ Development of α-Version SCWR Core Analysis Code
  - Incorporate COBRA3-C/P module into the nodal neutronics for improved T/H calculations,namely, VHTR conditions
- ➢ Validation of lattice physics code (HELIOS) for SCWR applications
- ➢ Conceptual design of a SCWR fuel assembly
  - Adopt cruciform solid water moderator concept instead of the existing 3x3 square water moderator Concept

SCWR Physics Activities

□ α-Version SCWR Core Analysis Code

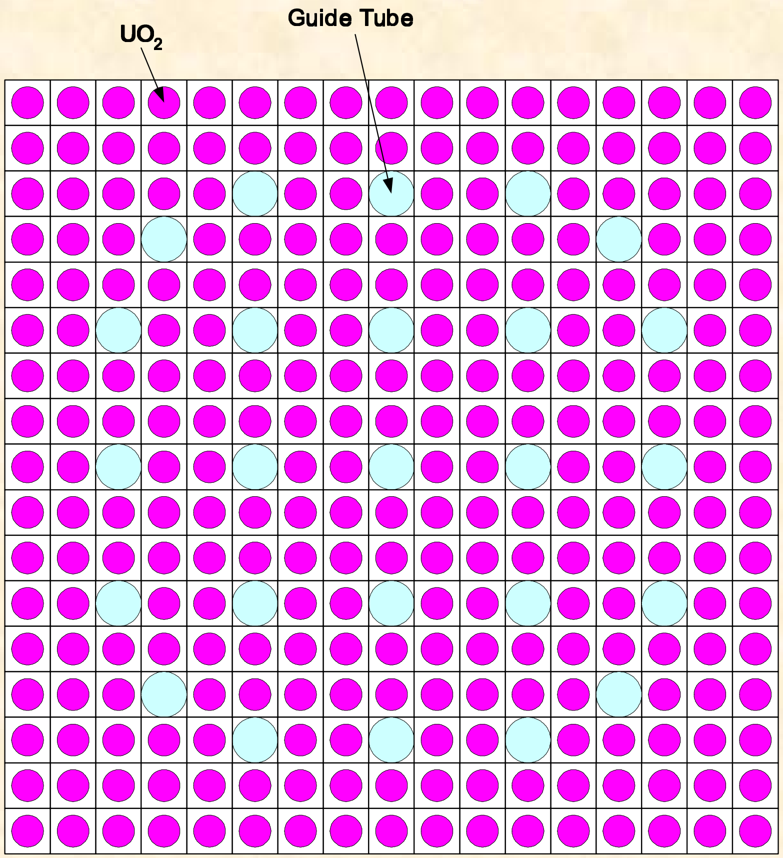
T/H Calc. Method of NUREC Code



SCWR Physics Activities

Validation of HELIOS lattice code for SCWR applications

- Developed by ANL
  (Ref.: MCNP4C, WIMS8)
- 17x17 PWR fuel assembly
- Fuel : UO_2 (5% enrichment)
  : Zircaloy-2 Clad
  : Water Density = 0.3g/cc
  : Room Temperature
- K-infinite, Power Distribution



Verification of Lattice Code for SCWR (HELIOS)

- **K-infinite**

  MCNP4C = 1.27325 ± 0.00028

  WIMS8 = 1.26938 (28-g)

  HELIOS-1.6 = 1.26899(45-g)

- **Pin Power Distribution**

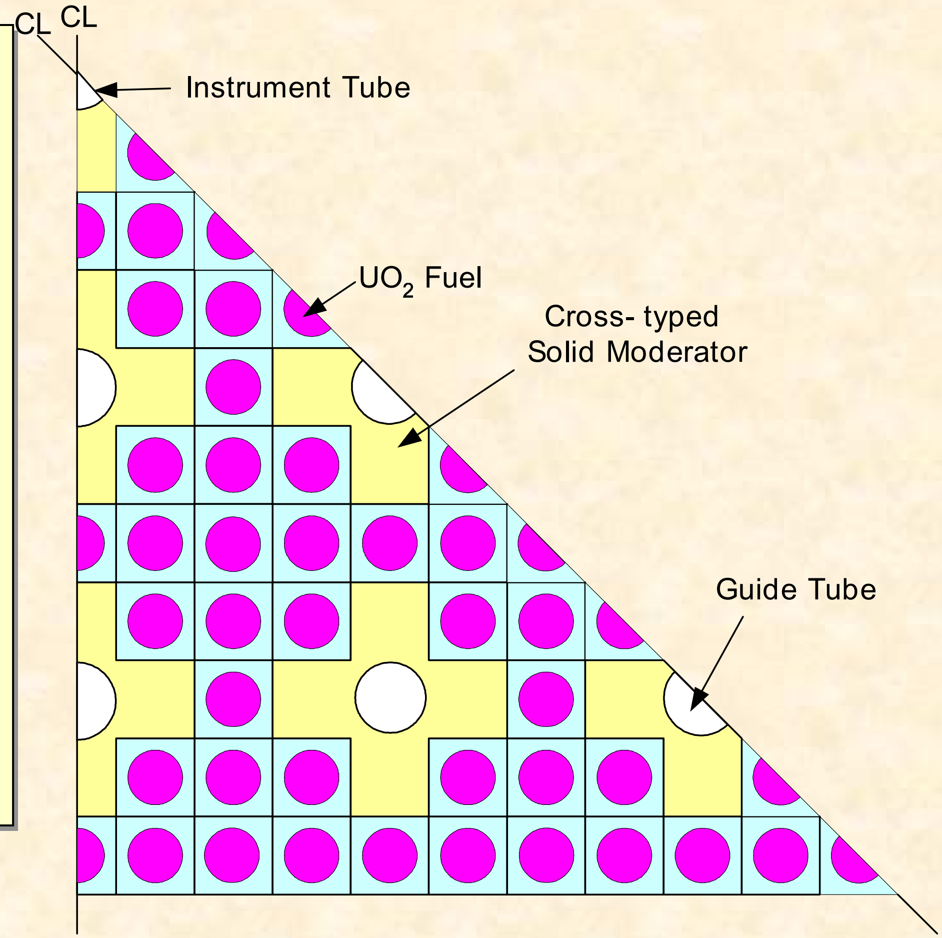
Normalized power of MCNP
Difference between WIMS8 and MCNP, %
Difference between HELIOS and MCNP, %

								0.949 0.3 0.7
							0.950 - 0.8 - 0.6	0.951 - 0.3 - 0.1
						0.970 0.8 0.8	0.953 0.2 0.3	0.958 - 0.7 - 0.8
						1.008 0.4 - 0.2	0.966 0.0 0.1	0.959 0.0 0.2
				1.037 - 0.5 - 0.4	1.045 - 0.2 - 0.6	1.028 0.3 0.0	0.993 - 0.6 - 0.4	0.967 0.3 0.5
				1.040 - 0.4 - 0.7	1.038 - 0.4 - 1.0		1.006 0.2 0.0	0.969 0.5 0.9
		1.020 - 0.3 0.2	1.036 - 0.5 - 0.8	1.017 - 0.2 0.0	1.007 0.4 0.4	1.015 0.6 0.2	0.988 0.6 0.6	0.975 0.0 0.3
	1.014 - 0.1 0.8	1.012 0.3 0.5	1.029 0.3 - 0.1	1.011 0.1 0.6	1.010 - 0.2 0.1	1.022 0.0 - 0.5	0.988 0.4 0.6	0.975 0.2 0.8
	1.035 - 0.2 - 0.2	1.041 - 1.0 - 0.8		1.034 - 0.6 - 1.2	1.031 - 0.6 - 0.9		1.010 0.1 0.1	0.972 0.5 0.6

SCWR Physics Activities

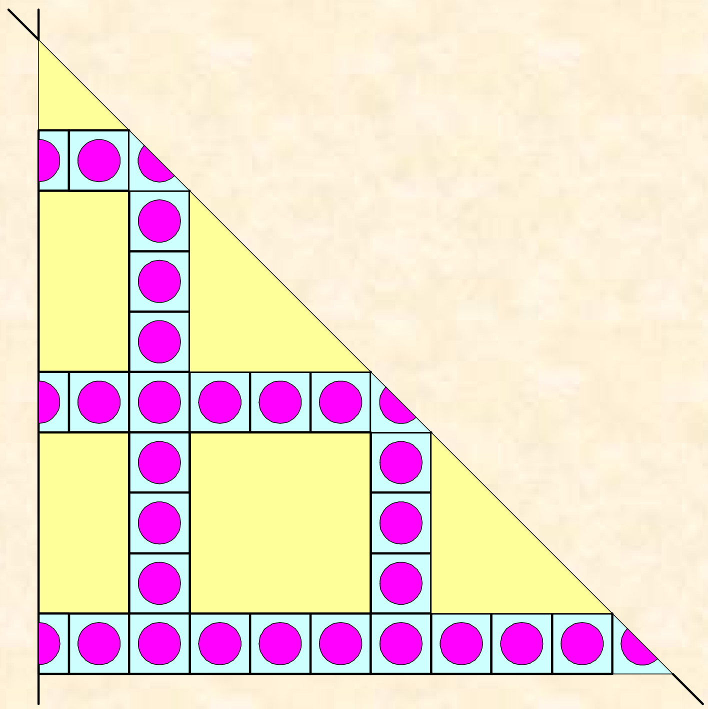
Conceptual design of SCWR fuel assembly

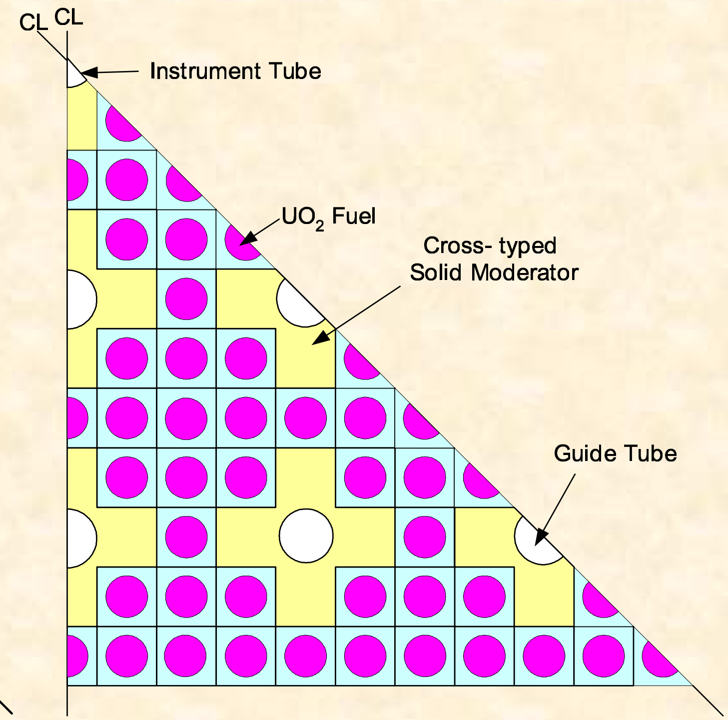
- 21×21 Rectangular Fuel Assembly
- Moderator Design
  - ☞ Cruciform Solid Moderator with ZrH_2
  - ☞ Fuel Volume Fraction
    - : 60% for 2×2 Moderator
    - : 50% for 3×3 Moderator
    - : 72% for Cruciform Moderator
  - ❖ reduce linear power density by loading more fuel pins



SCWR Physics Activities

Comparison of 3x3 Moderator vs. Cruciform Moderator





	3x3 Moderator	Cruciform Moderator
Fuel Fraction	50%	72%
No. of Fuel Rods	216	316
Relative Linear Power	1.45	1.0

SCWR Physics Activities

□ Outstanding Issues of SCWR Reactor Physics

- Establishment and Validation of SCWR Core Analysis Code
- Conceptual Design of SCWR Core
  - Conceptual Design of SCWR Fuel assembly
    - Optimum Implementation of Additional Moderator in Fuel assembly
  - Conceptual Design of SCWR Core
    - Reactivity Control during burnup (cf. no soluble boron)
    - Axial Power distribution control (cf. Tin~280 C; Tout~500 C; P~220 atm.)

DeCART 3-D Whole Core Transport Code

□ Development Purpose

- Provide high solution fidelity in the design analyses of new reactors involving highly heterogeneity

□ Features

- Generation of Sub-Pin Level Power Distribution
- Explicit Representation of Heterogeneous Core Geometry
  - No Homogenization
- Direct Acquisition of Multi-group Xsec Data from Library
  - No Group Condensation
  - Adaptive Resonance Treatment based on Subgroup Method
- Pin-wise Thermal Feedback
- Parallel Execution on SMP or LINUX Clusters
- Planar MOC Solution Based 3-D CMFD Formulation

□ Performance

- Can solve typical 3-D PWR problem within a few hours with ~20 CPUs
- Solution accuracy was demonstrated by using MCCARD Monte Carlo solutions

MC Code with Depletion and T/H Feedback

☐ MC-CARD : Monte Carlo Code for Advanced Reactor Design

- Personal computer-based, continuous energy and multi-group MC program written in C++ language
- Parallel computing capability with the help of MPI
- Designed exclusively for neutronics analysis of multiplying media, it is capable of depletion analysis and also can take into account thermal hydraulic feedback.

☐ Validation Calculations

- Neutronics analysis of VENUS critical facilities and a PWR plant (M&C '99, Madrid, Spain)
- Depletion characteristics of integral burnable absorber FA's of the current PWR (MC2000, Lisbon, Portugal)
- Verification of SMART Neutronics Design Methodology by the MCNAP Monte Carlo Code (2000 ANS Winter Mtg.)
- Error Propagation Module Implemented in the MC-CARD Monte Carlo Code (2002 ANS Summer Mtg.)
- Numerical Experiment on Variance Biases and Monte Carlo Neutronics Analysis with Thermal Hydraulic Feedback (SNA 2003, Paris, France)Thermal Hydraulic Feedback

Epilogue

- A Long, uphill, bumpy road ahead of Korean research teams in realizing the "real" GENIV reactors of their own, not the paper reactors.
- Brace for the tough mission ahead of them, with an often-cited proverb, "Well begun is half done."

"Keep the ball-rolling for another half, gentlemen.

Your mission is half accomplished."