NRC Evaluation Model Development

RIC 2010

Next Generation Nuclear Plant (NGNP) Research

J.M. Kelly
USNRC Research
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NRC EM Development

- **Objectives**
  - Develop confirmatory safety analysis capability (i.e., an Evaluation Model) to:
    - Support NGNP licensing review
    - Provide technical basis for regulatory decisions

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NRC EM Development

- **Evaluation Model**
  - Regulatory Guide (RG) 1.203:
    - *'An evaluation model (EM) is the calculational framework for evaluating the behavior of the reactor system during a postulated transient or design-basis accident. As such, the EM may include one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event.'*

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NRC EM Development

- **Scope:**
  - Radiological Consequences (Workers & Public)
    - Fission Product Release from Confinement/Containment
      - Nuclear Analysis
      - Thermo-Fluids
      - Fuel Performance
      - Fission Product Transport
      - Consequence Analysis
  - Applies to Pebble-Bed and Prismatic designs
  - Consists of three Evaluation Model's
    - Normal Operations (Pre-Break)
    - Initial Fission Product Release
    - Delayed Fission Product Release

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NRC EM Development

- **Evaluation Models**
  - Normal Operations
    - Determines the source term for the initial release.
      - i.e., the generation and distribution of FPs
        - » Magnitude and distribution of plate-out & absorbed FPs within Helium pressure boundary.
        - » Circulating activity: coolant contaminant & erosion activation products, and dust-born radionuclides.
  - Initial Release
    - Release of circulating activity including dust mobilization and lift-off of plated-out FPs.
    - Large/rapid reactivity events that result in CFP failures.
  - Delayed Release
    - Release of FPs from intact & failed CFPs during core heat up and w/wo ingress of air or steam.
    - FP hold-up and retention within the helium pressure boundary and the confinement.

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NRC EM Development

- **Examples of Transients to be Analyzed**
  - Pressurized loss-of-forced circulation (P-LOFC)
    - Temperature in upper vessel & associated components.
  - Depressurized loss-of-forced circulation (D-LOFC)
    - Peak fuel temperature; k_{eff} and RCCS performance.
  - Air Ingress following a D-LOFC
    - Graphite oxidation, integrity of core & support, CFP damage, release of fission products from graphite.
  - Reactivity Events, including ATWS
    - Control rod withdrawal, pebble-bed compaction, etc.
  - Water ingress
    - Reactivity insertion & chemical attack.

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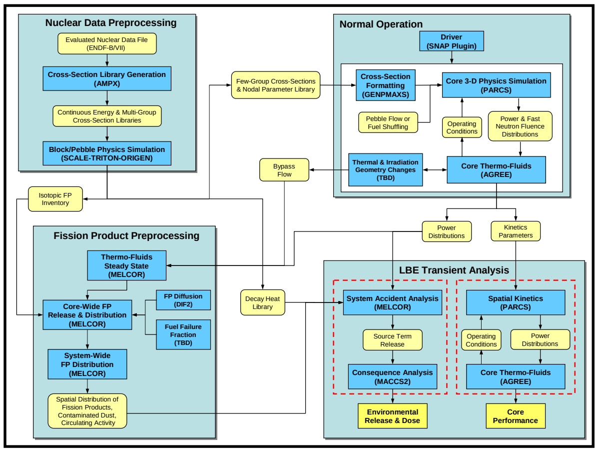

NRC EM Development

- **Development Tasks**
  - Code & Model Development
  - Code Integration
    - Automated workflow for EM code suite
  - Uncertainty Analysis Methodology
    - Implementation of statistical approach
      - e.g., Wilks' method
    - Incorporation of model bias & uncertainty factors into codes
  - PIRT Based Code Assessment
  - Code Applicability Report

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NGNP EM: Codes

- **MELCOR** - Severe Accident Code
  - 2D flow, heat transfer & fission product transport.
    - Completed Development Tasks:
      - Improved gas and material properties
      - Point reactor kinetics capability
      - Core heat transfer & flow models: PBR & PMR
      - Graphite oxidation models
      - Stratified counter-current flow model for air ingress
    - Ongoing Development Tasks:
      - Fission product release and transport models
      - Extend aerosol models to graphite dust transport
      - Reactor cavity cooling system model
      - Balance of plant models

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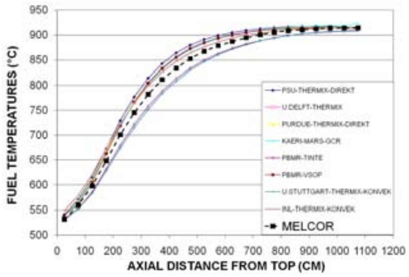
NGNP EM: Codes

- **MELCOR - Example**
  - PBMR-400 Steady State



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NGNP EM: Codes

- **PARCS -** Core Neutronics Simulator
  - Solves 3D, Time Dependent Core Flux/Power Equations
  - Solves 3D Flux in both Cylindrical (PBR) and Hexagonal (PMR)
    - Preliminary validation for PBR with OECD PBMR-400 Benchmark
  - Ongoing Development Tasks:
    - Triangle-Based Polynomial Expansion Method (TriPEN) for PMR
    - Improve Cross-Section Generation Capability
      - (e.g.) Core-Reflector interface treatment
    - Update Flux Solver:
      - Anisotropic Diffusion Coefficients
      - Coarse Mesh Finite Difference (CMFD) acceleration
    - Higher Order Transport Methods: SP-3
    - Computational Efficiency: OpenMP
    - Microscopic Depletion Capability

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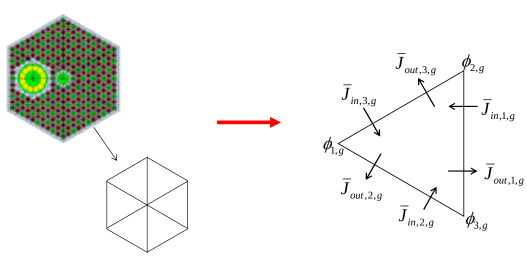
NGNP EM: Codes

- **PARCS -** TriPEN
  - Triangle-Based Polynomial Expansion Nodal Method



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NGNP EM: Codes

- **AGREE - A**dvanced **G**as **RE**actor **E**valuation
  - 3D, two-temperature porous medium (PBR) approach based on the legacy THERMIX/DIREKT codes.
  - Coupled to PARCS to provide coupled time-dependent neutronics and thermo-fluid solution for gas reactors
    - Preliminary validation with SANA Test Data and OECD PBMR-400 Benchmark
    - Used to check scaling of OSU-HTTF integral test facility
  - Ongoing Development Tasks:
    - Extension to model prismatic (PMR) core using r-θ-z geometry
    - New PMR modeling capability:
      - 3-D heat transfer model using TriPEN
      - Coolant channel and bypass flow using subchannel approach
    - Improved Numerics:
      - More implicit coupling between field equations
      - Parallel processing using OpenMP and multi-threaded solvers

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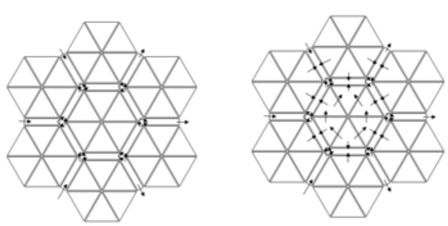
NGNP EM: Codes

- **AGREE -** PMR Bypass Flow Model
  - 3-D core represented by a series of cross-connected subchannels
  - Subchannel method is based on proven LWR core thermal-hydraulic analysis techniques (ie. COBRA/VIPRE)



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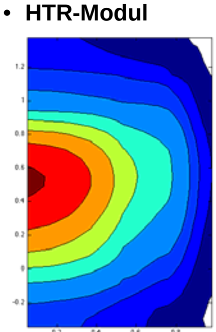
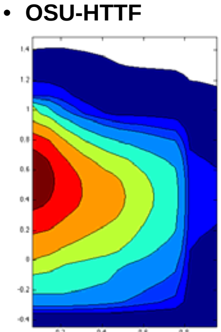
AGREE Example

- **HTR-Modul**



- **OSU-HTTF**



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NGNP EM: Codes

- **SCALE/AMPX -** Nuclear Analysis Code Suite
  - AMPX processes ENDF nuclear data into code usable libraries
  - SCALE provides lattice physics and depletion capabilities to generate few-group cross-sections, decay heat and FP inventory.
    - Double Heterogeneity Model implemented
      - Uses layered continuous energy CENTRM calculations for self shielding
        - » Calculated kernel specific disadvantage factors
        - » Does not rely on Dancoff Factors
    - Work in progress:
      - Benchmarking vs. HTTR, HTR-10 and PROTEUS
      - Detailed models of NGNP for sensitivity & parametric studies
      - Improve & validate interface to PARCS
      - Interface for fission product release calculations

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NGNP EM: Codes

- **SNAP - S**ymbolic **N**uclear **A**nalysis **P**rogram
  - Graphical User Interface Toolkit for NRC Codes
    - GUI for both pre- and post-processing
      - MELCOR
      - PARCS/AGREE
    - Plug-in capability, for example:
      - Driver code for steady-state normal operation
        - » Equilibrium core for PBR
        - » Fuel shuffling methodology for PMR
    - Auto Validation Tool
    - Uncertainty Analysis Tool

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NRC EM Development

- **Summary**
  - Code and model development tasks are underway.
  - Preliminary code assessment vs. existing database will begin in 2010.
  - Independent confirmatory analysis capability to be ready in 2013.

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