U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

NRC Evaluation Model Development

RIC 2010

Next Generation Nuclear Plant (NGNP) 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

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.'*

NRC EM Development

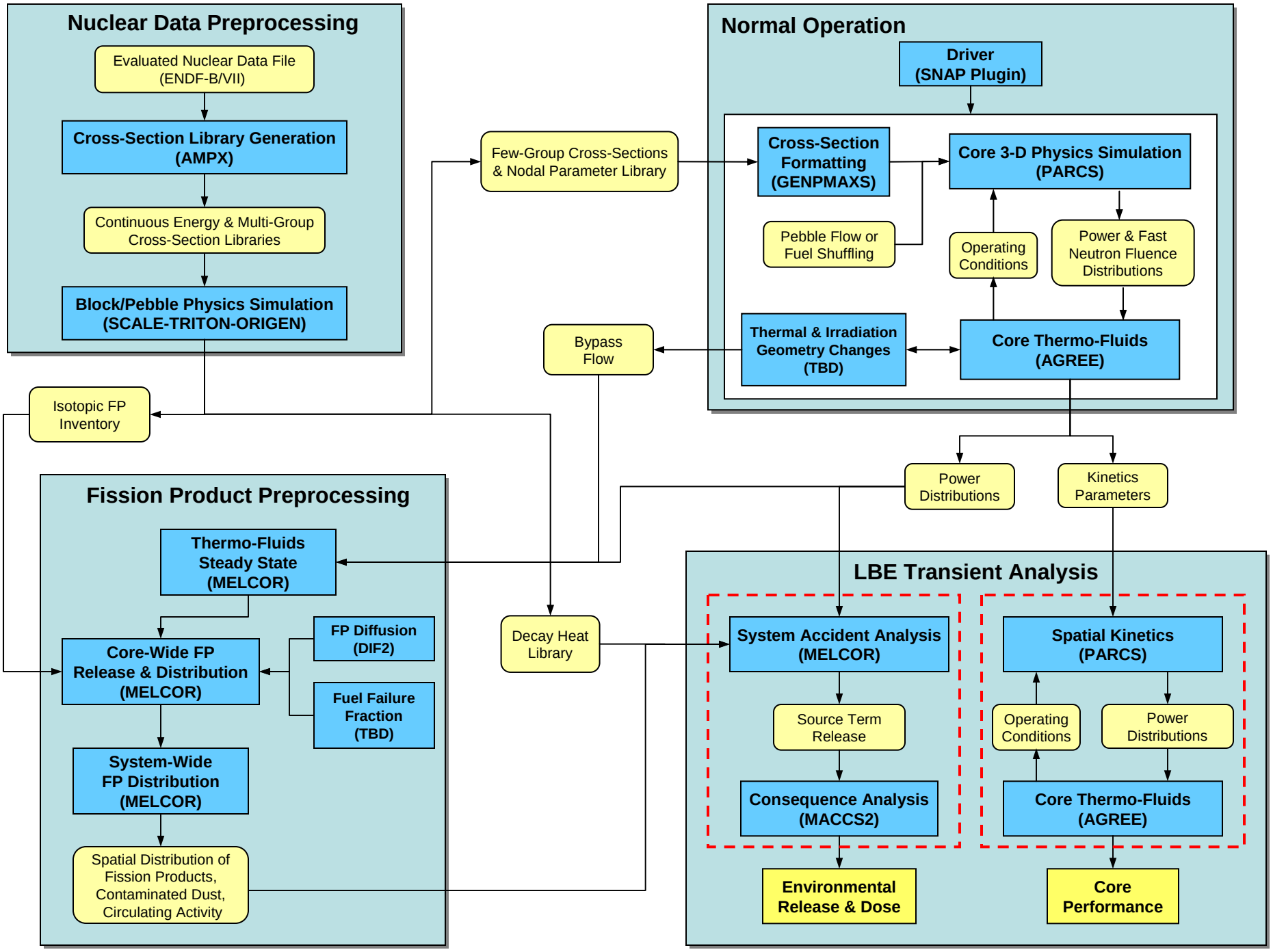
- **Scope:**
  - Radiological Consequences (Workers & Public)
    - Fission Product Release from Confinement/Containment
      - Nuclear Analysis
      - Thermo-Fluids
      - Fuel Performance
      - Fission Product Transport
      - Consequence Analysis
  - Applies to Pebble-Bed and Prismatic designs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

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.

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.


Nuclear Data Preprocessing
Evaluated Nuclear Data File (ENDF-B/VII)
Cross-Section Library Generation (AMPX)
Continuous Energy & Multi-Group Cross-Section Libraries
Block/Pebble Physics Simulation (SCALE-TRITON-ORIGEN)
Isotopic FP Inventory
Few-Group Cross-Sections & Nodal Parameter Library
Normal Operation
Driver (SNAP Plugin)
Cross-Section Formatting (GENPMAXS)
Core 3-D Physics Simulation (PARCS)
Pebble Flow or Fuel Shuffling
Operating Conditions
Power & Fast Neutron Fluence Distributions
Thermal & Irradiation Geometry Changes (TBD)
Core Thermo-Fluids (AGREE)
Bypass Flow
Power Distributions
Kinetics Parameters
Fission Product Preprocessing
Thermo-Fluids Steady State (MELCOR)
Core-Wide FP Release & Distribution (MELCOR)
FP Diffusion (DIF2)
Fuel Failure Fraction (TBD)
System-Wide FP Distribution (MELCOR)
Spatial Distribution of Fission Products, Contaminated Dust, Circulating Activity
Decay Heat Library
LBE Transient Analysis
System Accident Analysis (MELCOR)
Source Term Release
Consequence Analysis (MACCS2)
Spatial Kinetics (PARCS)
Operating Conditions
Power Distributions
Core Thermo-Fluids (AGREE)
Environmental Release & Dose
Core Performance

NRC EM Development

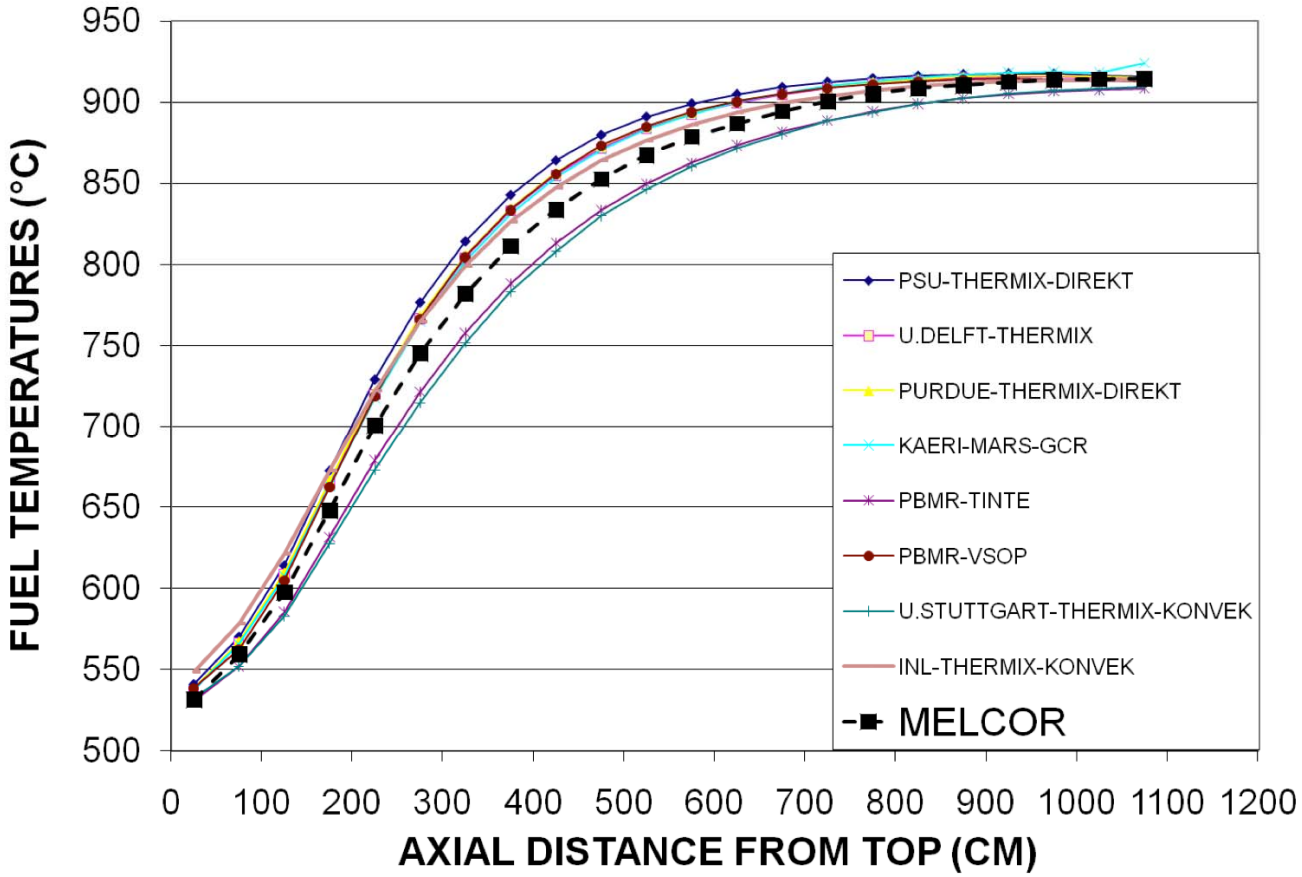
- **Development Tasks**
  - Code & Model Development
  - Code Integration
    - Automated workflow for EM code suite
  - Uncertainty Analysis Methodology
    - Implementation of statistical approach
      - e.g., Wilks' method
    - Incorporation of model bias & uncertainty factors into codes
  - PIRT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

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

NGNP EM: Codes

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

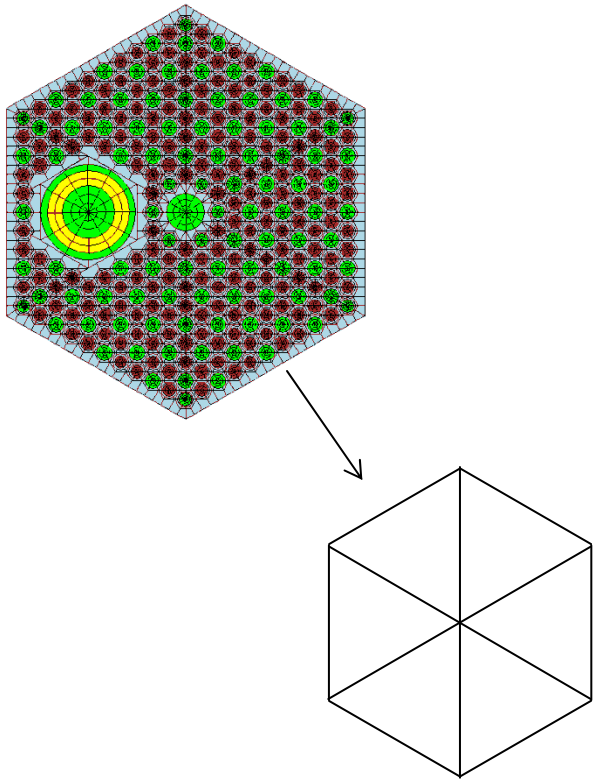


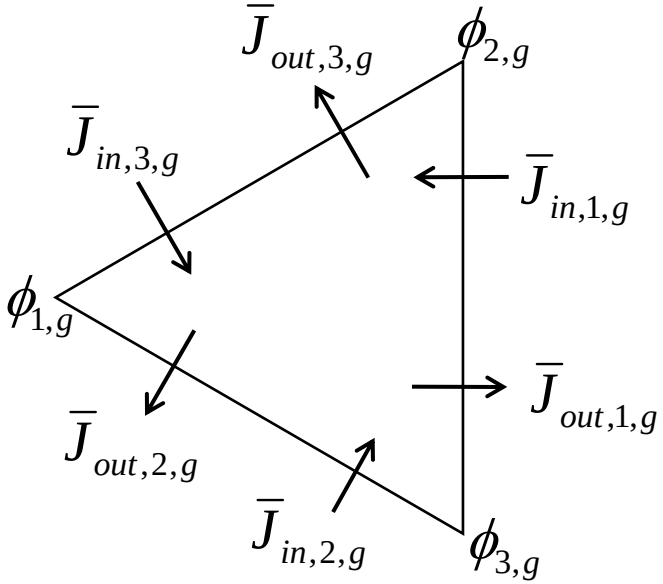
NGNP EM: Codes

- **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

NGNP EM: Codes

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



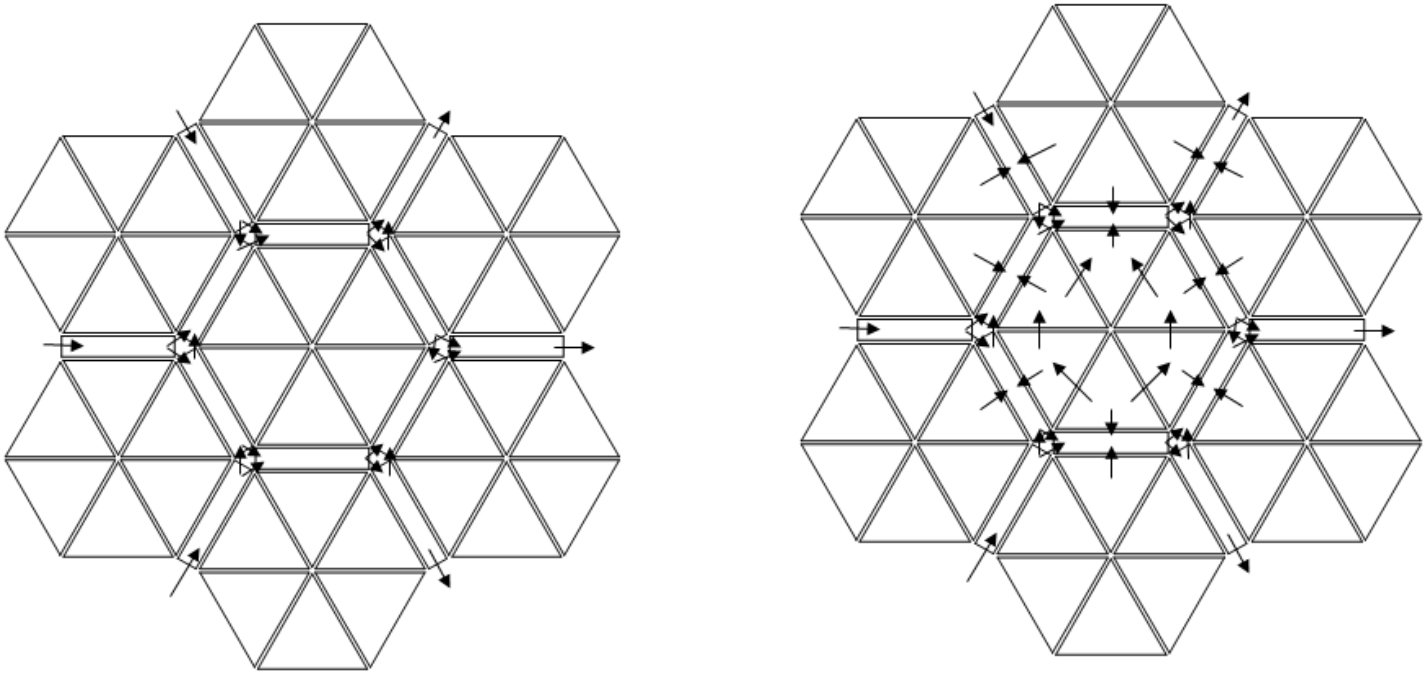


NGNP EM: Codes

- **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

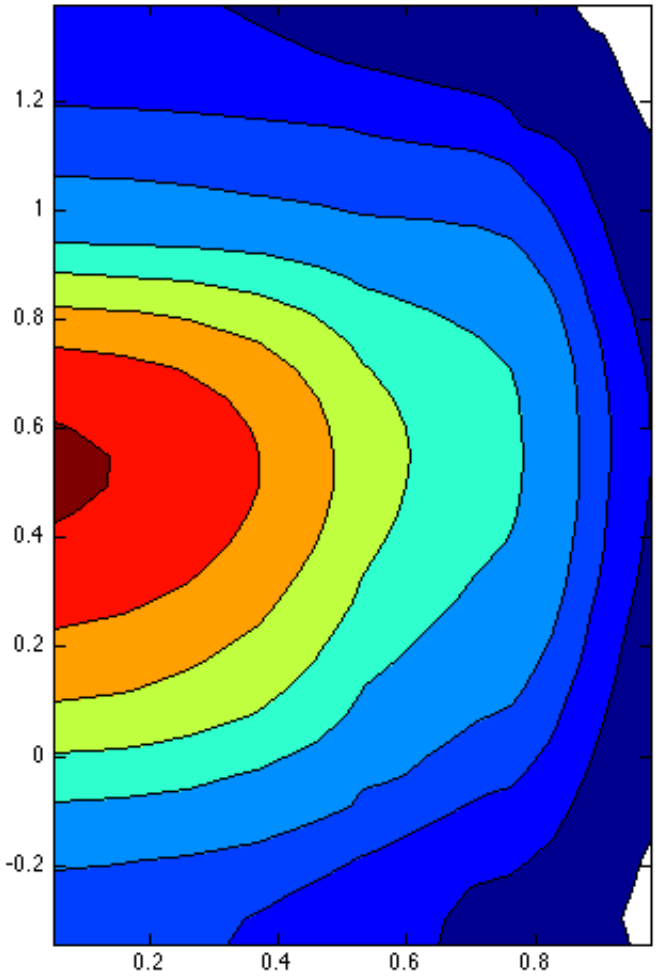
NGNP EM: Codes

- **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)

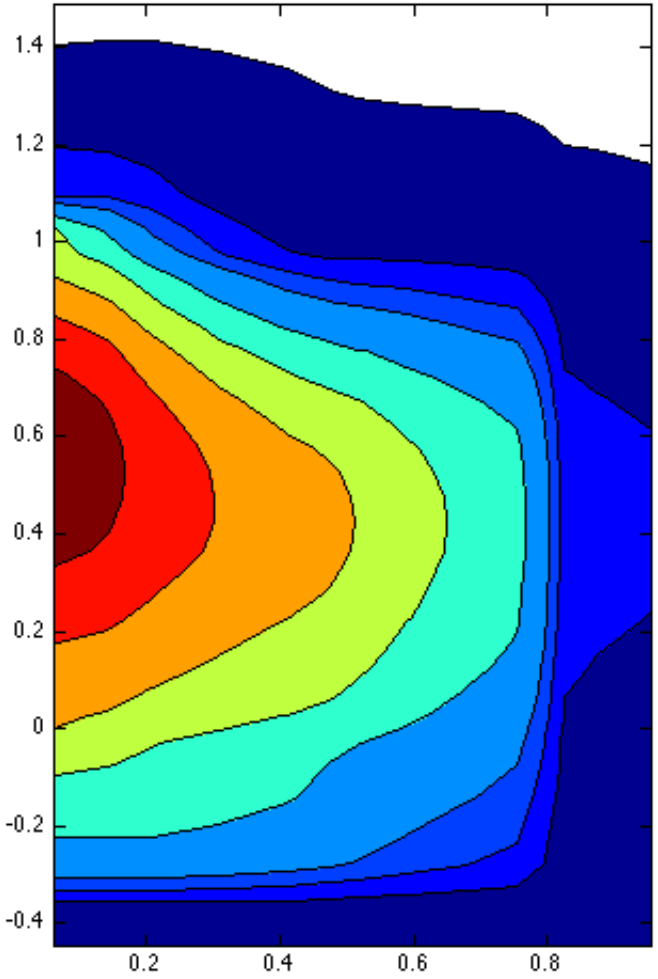


AGREE Example

- **HTR-Modul**



- **OSU-HTTF**



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

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

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.