MASTER: REACTOR CORE DESIGN AND ANALYSIS CODE

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ABSTRACT

1. Program Name and Title: MASTER: Reactor Core Design and Analysis Code.[1]

2. Computers and Operating Systems for Which Program is Available: UNIX-based workstations and Windows-based Personal Computers.

3. Problem Solved: MASTER code solves the space- and time-dependent multi-group neutron diffusion equation in three-dimensional Cartesian and hexagonal geometries. It is used for full scope reactor core design and analysis for an integral reactor SMART and commercial PWRs of the leading vendors such as Westinghouse and ABB-CE in Korea. It also solves the depletion problem using microscopic cross sections. The other problems that are solved in MASTER include fuel pin power, pin burnup, xenon dynamics, adjoint flux, three-dimensional power shape matching, in-core and ex-core detector signal evaluation, thermal hydraulics (T/H), and design specific activities including fuel management.

4. Method of Solution: The time-dependent multi-group neutron diffusions are discretized in both space and time. MASTER has several nodal solution methods for spatial discretization: NEM[2]/NIM[3] hybrid method, AFEN[4], and non-linear NEM[5]/ANM[6] for Cartesian geometry, and non-linear TPEN[7] and AFEN[8] for hexagonal geometry. Additional neutronics solvers are also available for cross comparisons of accuracy and efficiency between the methods. The resulting time-dependent nodal equations are solved with the implicit first order Euler method combined with frequency transformation. The iterative nodal solution process is accelerated either by the coarse-mesh rebalancing or by the coarse-mesh finite difference formulation.

MASTER has the microscopic depletion module consistent with the spectral codes: CASMO-3[9] and HELIOS.[10] Fuel depletion is performed with the predictor-corrector method for Uranium, Plutonium, Thorium, and multiple burnable poison chains.

Two different core T/H calculation modules are available, which can be optionally used depending upon the nature of problems to be solved: one is the fuel temperature versus linear power density table for simple T/H calculations and the other is the detailed T/H codes, COBRA3-C/P[11] and MATRA[12], which are integrated into the MASTER code for the simulation of more sophisticated transient reactor conditions in view of T/H.

MASTER calculates the local heterogeneous fuel pin power distributions in each axial segment within the fuel assembly by modulation of the local homogeneous distributions based on an analytic solution method and heterogeneous power formfunctions. The fuel pin burnup is then directly calculated from the fuel pin power integration over time.

5. Restrictions on the Complexity of the Problem: The maximum number of energy groups and mesh points are only limited by the physical memory of the platform machine. In practice, however, maximum energy groups and maximum mesh points are restricted as 12 and 50000, respectively.

6. Typica1 Running Time: The following tables give some typical cpu time for MASTER depletion and transient computations on a Pentinum IV 800 MHz Personal Computer.

A. Case 1 - Depletion Calculation

Yonggwang Unit 3 Cycle 1, three-dimensional, two energy groups, quarter core, 4 nodes per fuel assembly, 6266 nodes (241 radial nodes, 26 axial nodes), 17 depletion steps, 10^{-5} convergence criteria on flux, nonlinear ANM

Solution Type	cpu seconds (fraction, %)
Nodal Solution	46.4 (32.1%)
Depletion	11.9 (8.2%)
Thermal-Hydraulic Solution	8.1 (5.6%)
Fuel Pin Power and Burnup	8.3 (5.7%)
Read and Update Cross Sections and Others	69.7 (48.2%)
Total	144.4 (100%)

B. Case 2 - Transient Calculation

NEACRP A1 Benchmark[13], three-dimensional, two energy groups, 3978 nodes (221 radial nodes, 18 axial nodes), 500 time steps (Δt=0.002 second for 1.0 second simulation time), 10^{-5} convergence criteria on flux, nonlinear NEM

Solution Type	cpu seconds (fraction, %)
Nodal Solution	36.1 (40.6%)
Thermal-Hydraulic Solution	27.5 (30.9%)
Read and Update Cross Sections and Others	25.4 (28.5%)
Total	89.0 (100%)

7. Unusual Features of the Program: Multiple nodal solution options are available. All functional modules of steady-state, depletion, transient, and T/H are seamlessly integrated in the MASTER code so that no additional effort is required for interfacing or transferring data between them. It also has versatile applicability to various types of reactor core design and analysis including WH-PWRs, ABB-CE-PWRs, KNGR, SMART, VVER, and BWRs.

MASTER is integrated with a multi-dimensional system T/H code to constitute a coupled system T/H and reactor kinetics code, MARS/MASTER.[14] A detailed accident analysis is thus possible by the three-dimension neutronics and T/H coupled calculation with an on-line time-dependent DNB evaluation.[15]

8. Related and Auxiliary Programs: The PROLOG code[16] is the interface program between MASTER and CASMO-3 or HELIOS and it generates the microscopic cross section library for MASTER.

9. Hardware Requirements: The amount of memory required is problem dependent. In practice, 200 Mbyte RAM on PC is enough for the two-group, three-dimension, and full core analysis of typical PWRs.

10. Programming Language(s): FORTRAN 90.

11. Other Programming or Operating Information or Restrictions: None.

12. References:

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13. Appendix: Uncertainty evaluations were performed through a whole spectrum of benchmark calculations and comparisons with various plant measurement data for verification and validation. Through the approval of Topical Report on the Uncertainties of CASMO-3/MASTER for Reference of License Application by Ministry of Science and Technology of Republic of Korea, MASTER demonstrated its superior accuracy for the core design and safety analysis of PWRs. MASTER-3.0 is currently used for design and analysis of an integral reactor SMART.