

How the PMAXS systems operates

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U.S. DEPARTMENT OF
ENERGY

Learning goals



Gain insight into PMAX's purpose and its role



Become familiar with how PMAX functionalizes cross sections and its data structure

Instantaneous and History Variables

Instantaneous Variables

1. CR control rod fraction (Required)
2. DC density of coolant
3. PC soluble poison in coolant
4. TF temperature of fuel
5. TC temperature of coolant
6. IC impurity of coolant
7. DM density of moderator
8. PM soluble poison in moderator
9. TM temperature of moderator
10. IC impurity of moderator (CANDU)
11. DN density difference between neighbor and current node (CANDU)
12. BN burnup difference between neighbor and current node (CANDU)

History Variables

1. CR control rod fraction
2. DC density of coolant
3. PC soluble poison in coolant
4. TF temperature of fuel
5. TC temperature of coolant

History variables are burnup (B) and burnup weighted quantities, such as control rod history

$$HCr(B_0) = \frac{\int_0^{B_0} Cr(B) dB}{B_0}$$

XS / Kinetics Parameters TH Dependent Quantities

- Macroscopic XS

$$\Sigma_a, \Sigma_{tr}, \Sigma_f, \nu\Sigma_f, \kappa\Sigma_f, \Sigma_{g \rightarrow g'}$$

- Discontinuity Factors

$$ADF, CDF, ZDF$$

- Xenon / Samarium & Detector

$$\sigma_a^{Xe}, \sigma_a^{Sm}, \sigma_a^{Detector}$$

- Groupwise form functions

$$GFFs[ng, npin]$$

- Direct Energy Deposition

$$DED[4], J1[:]$$

XS / Kinetics Parameters

TH Invariant Quantities

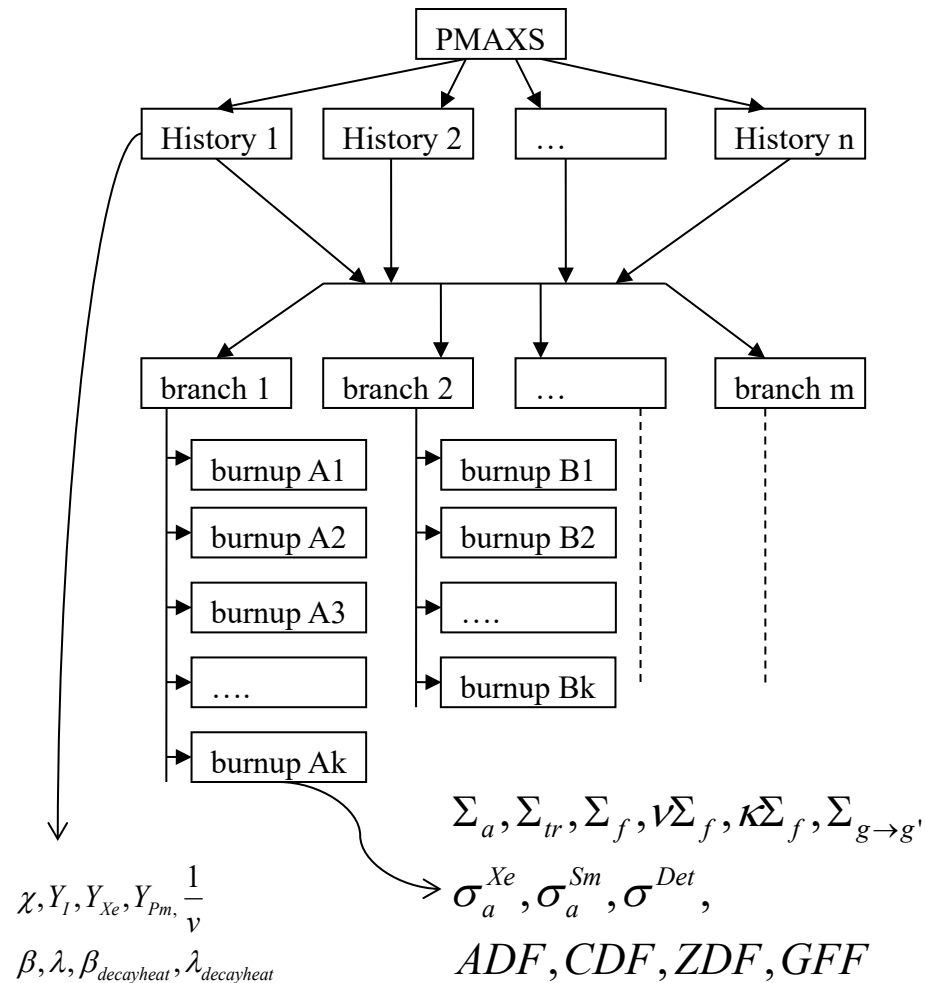
- In order to reduce memory and computation cost, the following quantities depend only on history variables and burnup:
 - Primary Kinetics Data:
$$\chi, \lambda, \beta, \frac{1}{\nu}, Yld_{I-135}, Yld_{Xe-135}, Yld_{Pm-149}$$
 - Secondary Kinetics Data:
$$\lambda_{decayheat}, \beta_{decayheat}$$
- Previously GFF depended up burnup and history only
 - This proved to be inadequate for BWR modeling

PMAXS Model – General Approach

$$\begin{aligned}\Sigma(C, Dc, \sqrt{Tf}, Tc) = & \Sigma^r(Dc^r, \sqrt{Tf}^r, Tc^r) + \sum_i c_i \Delta \Sigma^i(Dc^r, \sqrt{Tf}^r, Tc^r) \\ & + \Delta Dc \left. \frac{\partial \Sigma}{\partial Dc} \right|_{(C, Dc^m, \sqrt{Tf}^r, Tc^r)} + \Delta \sqrt{Tf} \left. \frac{\partial \Sigma}{\partial \sqrt{Tf}} \right|_{(C, Dc, \sqrt{Tf}^m, Tc^r)} \\ & + \Delta Tc \left. \frac{\partial \Sigma}{\partial Tc} \right|_{(C, Dc, \sqrt{Tf}, Tc^m)}\end{aligned}$$

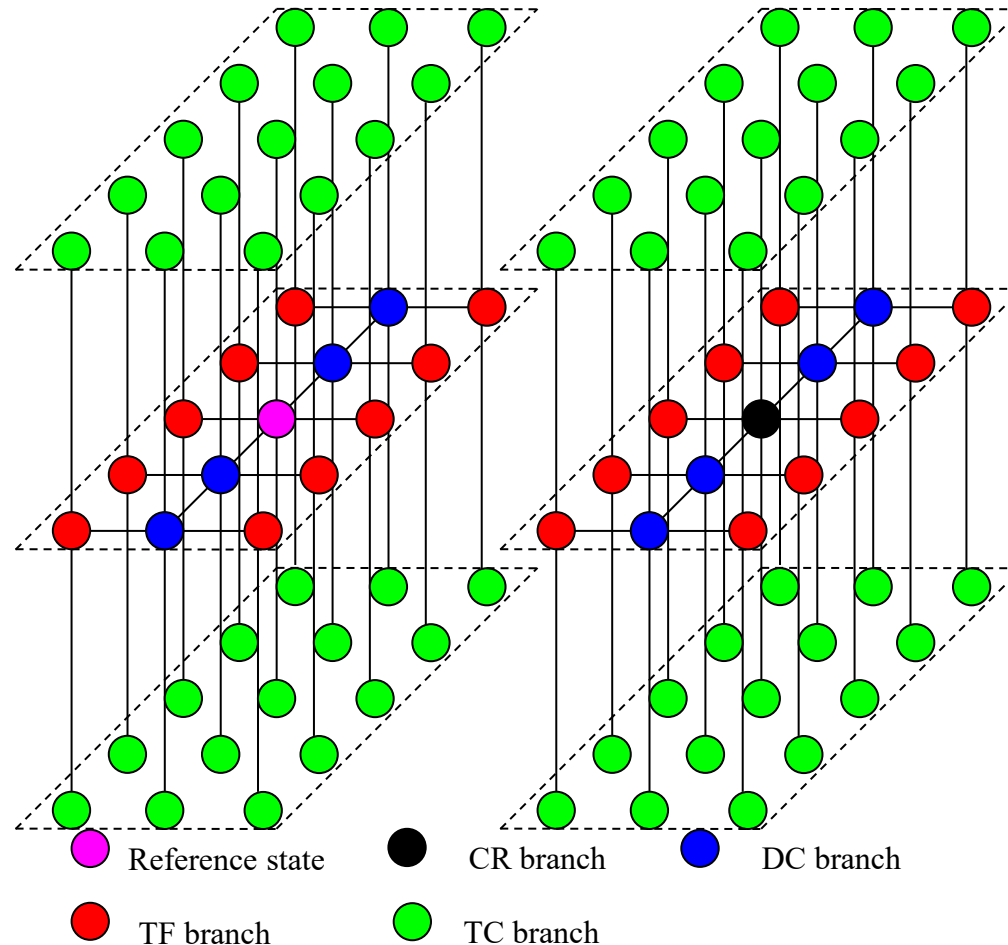
- $C = \{c_1, c_2, \dots\}$: fractions for each type of CR; $\Delta \Sigma^i$: XS for i th type CR
- Dc : Coolant Density; Tf : Fuel temperature; Tc : Coolant temperature;
- Super script:
 - r : reference value
 - m : middle value between current and reference state

PMAXS Data Structure



- PMAXS contains 1 or more history cases. Data points with same history values (except burnup) form a history case.
- Every History contains same number of branches. Data points with same instantaneous state values form a branch.
- Each branch contains 1 or more burnup points which may vary between branches.
- Each branch burnup point contains cross sections shown bottom right
- Each history burnup point contains kinetics data shown at bottom left

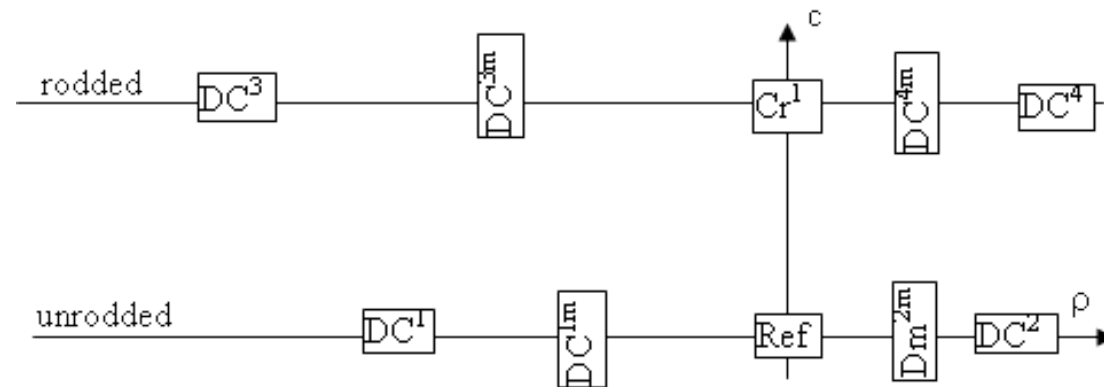
PMAXS with Multi-Dimensional Table Data Points



- 90 data points:
 - 1 reference state
 - 1 CR (control rod) branch
 - 8 DC (coolant density) branches
 - 20 TF (fuel temperature) branches
 - 60 TC (coolant temperature) branches
- At most 30 points can be involved in evaluating XS at given condition for PMAXS model, while at most 16 points can be involved for piece-wise linear interpolation model

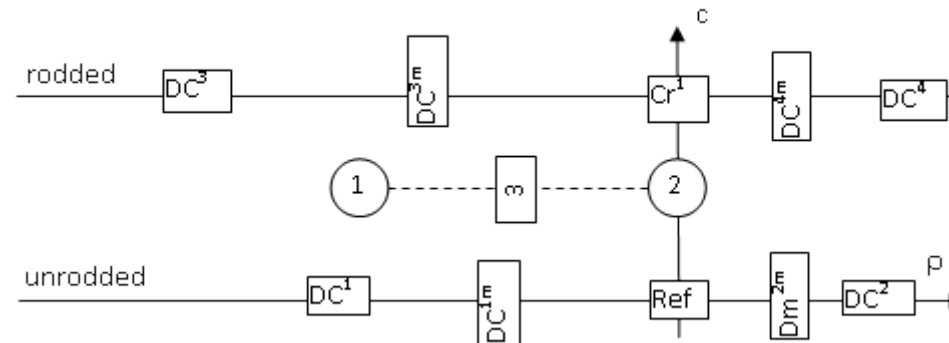
Generating Branches

- From the Reference branch, change one variable at a time in PMAXS order to generate different branch cases
- there are 6 states “Ref”, “Cr1”, “DC1”, “DC2”, “DC3”, “DC4”, at which cross sections are provided from the lattice code.
- In PMAXS, the original XS at the “Ref” state are stored as the Reference branch. The difference of the cross sections between the “DC¹” state and the “Ref” state are stored in the “DC^{1m}” branch.



Generating Branches (cont.)

- The partial derivatives with respect to the density of coolant at the states “DC1m”, “DC2m”, “DC3m” and “DC4m” are computed with data from the 6 states “DC1”, “DC2”, “DC3”, “DC4” and “Ref”, “Cr1”.
- These partial derivatives are then stored as 4 branch cases of the coolant density in PMAXS.

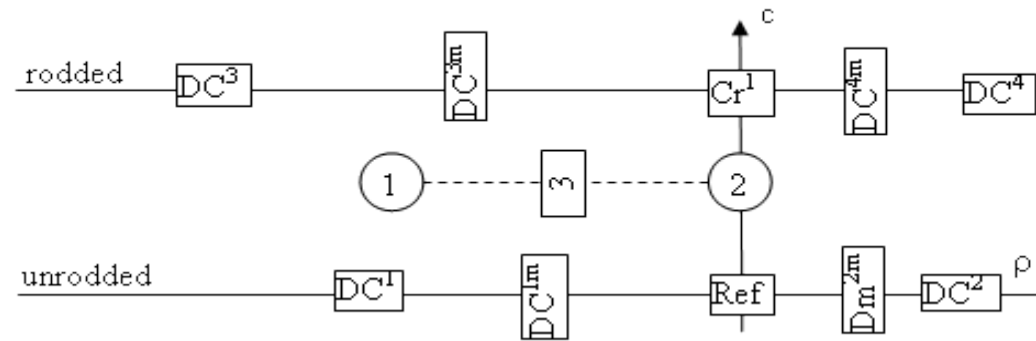


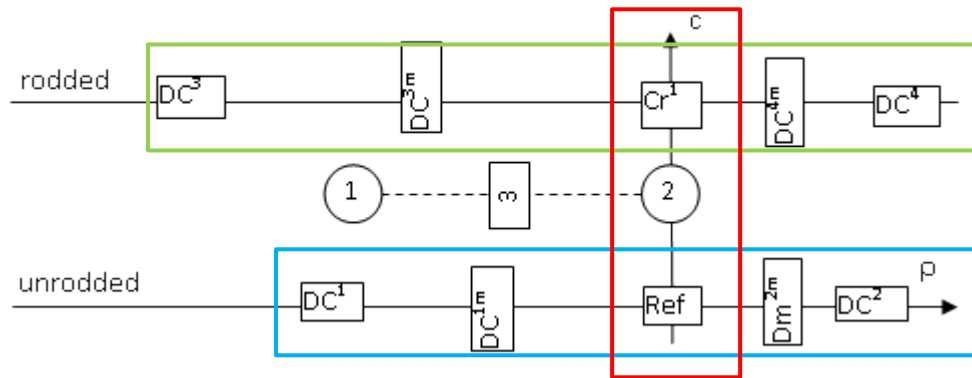
Instantaneous Feedback

- The feedback formulation for this example can be simplified as

$$\Sigma(c, DC) = \Sigma^r + c\Delta\Sigma^1 + (DC - DC^r) \left. \frac{\partial \Sigma}{\partial DC} \right|_{(c, DC^m)}$$

- To compute XS at point 1, we need the partial derivative with respect to density of the coolant at point 3, which can be obtained by linear interpolation between partial derivatives at “DC1m”, “DC2m”, “DC3m”, “DC4m”.





Instantaneous Example

$$\Sigma(c, DC) = \Sigma^r + c \frac{\partial \Sigma}{\partial Cr} \bigg|_{(Cr^1/2)} + (DC - DC^r) \frac{\partial \Sigma}{\partial DC} \bigg|_{(c, DC^m)}$$

$$\frac{\partial \Sigma}{\partial Cr} \bigg|_{(Cr^1/2)} = \frac{(\Sigma_{Cr1} - \Sigma_{Ref})}{(1-0)}$$

$$\frac{\partial \Sigma}{\partial DC} \bigg|_{(c, DC^m)} = w_1 \frac{\partial \Sigma}{\partial DC} \bigg|_{(0, DC^{1m})} + w_2 \frac{\partial \Sigma}{\partial DC} \bigg|_{(0, DC^{2m})} + w_3 \frac{\partial \Sigma}{\partial DC} \bigg|_{(1, DC^{3m})} + w_4 \frac{\partial \Sigma}{\partial DC} \bigg|_{(1, DC^{4m})}$$

$$w_1 = (1-c) \frac{DC - DC^2}{DC^1 - DC^2} \quad w_2 = (1-c) \left(1 - \frac{DC - DC^2}{DC^1 - DC^2} \right)$$

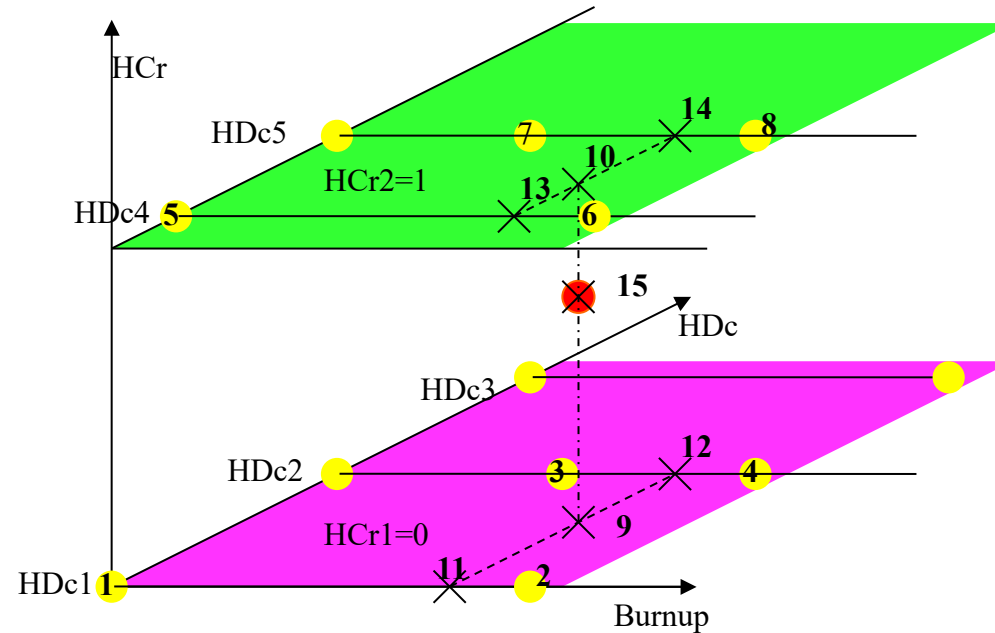
$$w_3 = c \frac{DC - DC^4}{DC^3 - DC^4} \quad w_4 = c \left(1 - \frac{DC - DC^4}{DC^3 - DC^4} \right)$$

Equivalent to:

$$\frac{DC^1 - DC}{DC^1 - DC^2}$$

History Dependence: History States and Burnup

- PARCS accepts five history variables:
HCR,HDC,HPC,HTF,HTC as functions of burnup
- History dependence are treated by linear interpolation
 - First, use linear interpolation to find the weights for data points (1-8) surrounding the point of interest (15)
- Data points can be in irregular structure
- Tradeoff Between Memory Requirements and Speed



PMAXS Model: Complete Expression

$$\Sigma_i(S, N, H) = \Sigma^r(H) + \Delta \Sigma_i^{CR}(H) + \sum_{j=2}^{N_s} \Delta s_j \left. \frac{\partial \Sigma_i}{\partial s_j} \right| (S_j^m, N^r, H)$$

$$\Sigma(C, S, N, H) = \sum_{i=0}^{N_c} c_i \Sigma_i(S, N, H) + \sum_{j=1}^4 \left(\sum_{k=1}^{N_n} n_{j,k} \left. \frac{\partial \Sigma_i}{\partial n_k} \right| (S, N_{j,k}^m, H) \right)$$

- $C = \{c_1, c_2, \dots\}$: fractions for each type of CR;
- $S = \{S_2, S_3, \dots, S_{10}\} = \{DC, PC, TF, TC, IC, DM, PM, TM, IM\}$ state variables of current node
- N : state value differences between neighbors and current nodes
- H : history variables (burnup, control rod history, coolant density history, etc).

Acknowledgments

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