An approximation method of determining initial core design parameters with a given energy requirement

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Contents

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1.1 Purpose of work

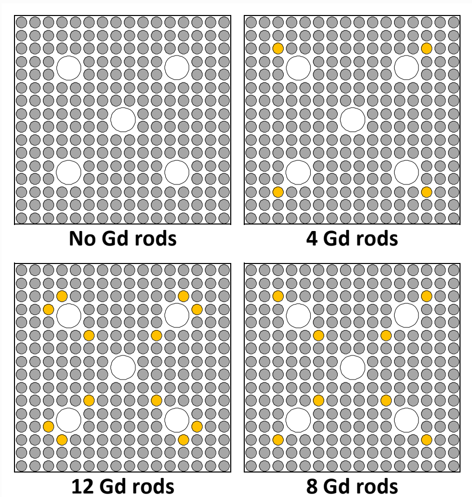
- Creating a **practical tool** i.e. a graphical method **to reduce the time** of determining chosen target parameters for the initial reactor **loading pattern.**

- **Target parameters:**
  - Average core enrichment
  - Total number of BA rods in core
- **Constraints:**
  - Required cycle length
  - Critical boron concentration at BOC

1.2 Background of study

Initial stage

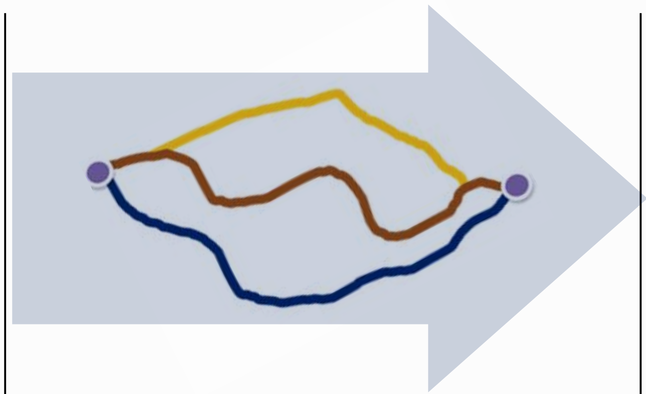
Given Fuel Assemblies



Constraints to be met:

Cycle length
CBC at BOC

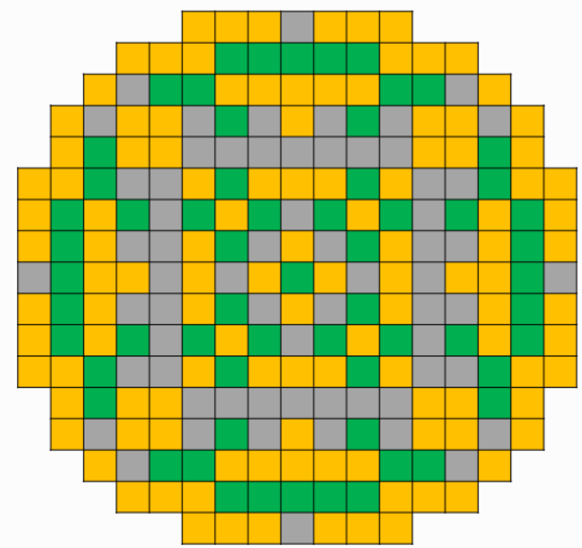
Intermediate stage



- **Usually based on commercial design experience.**
- **Time consuming process.**

Final stage

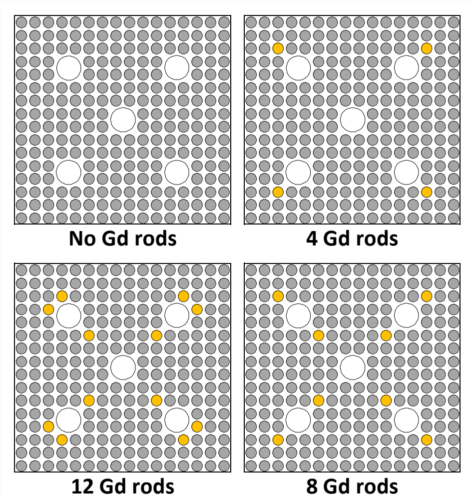
Initial loading pattern



1.3 Fuel Management Net Graph (FMNG)

Initial stage | **Intermediate stage** | **Final stage**

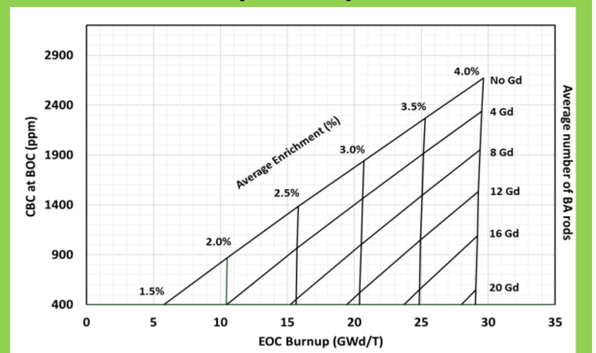
Given
Fuel Assemblies



Constraints to be met:

Cycle length
CBC at BOC

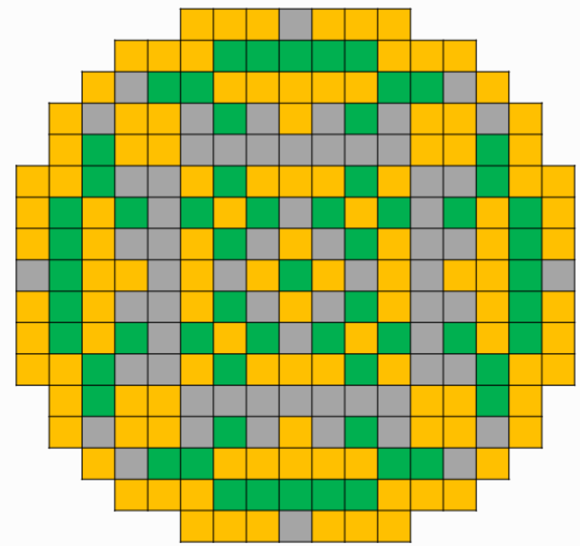
Fuel Management Net Graph
(FMNG)



Use **target parameters** given by the FMNG in creating a batch of fuel for the initial LP:

- **Required average core enrichment**
- **Required total number of BA rods in core**

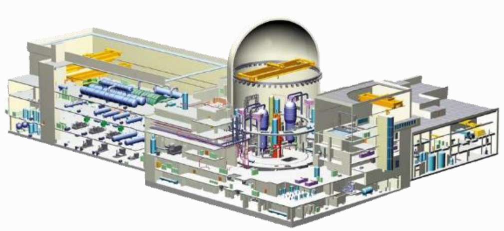
Initial loading pattern

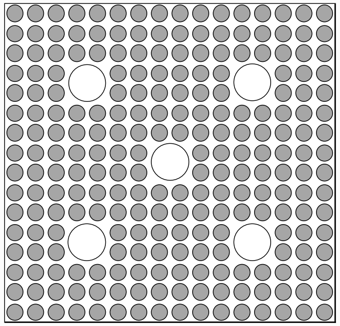


2. Input model

APR1400 reactor model
(Shin-Kori Unit 3)

Thermal Hydraulic Data	Quantity
Thermal Power (MWt)	3983
Operating Pressure (bar)	155.13
Design Pressure (bar)	155.13
Moderator Temperature (K / °F)	582.05 / 588.02
Cold leg Temperature (K / °F)	563.75 / 555.08
Hot Leg Temperature (K / °F)	600.35 / 620.96
Nominal Design Flow ([kg/m²-sec)	3480

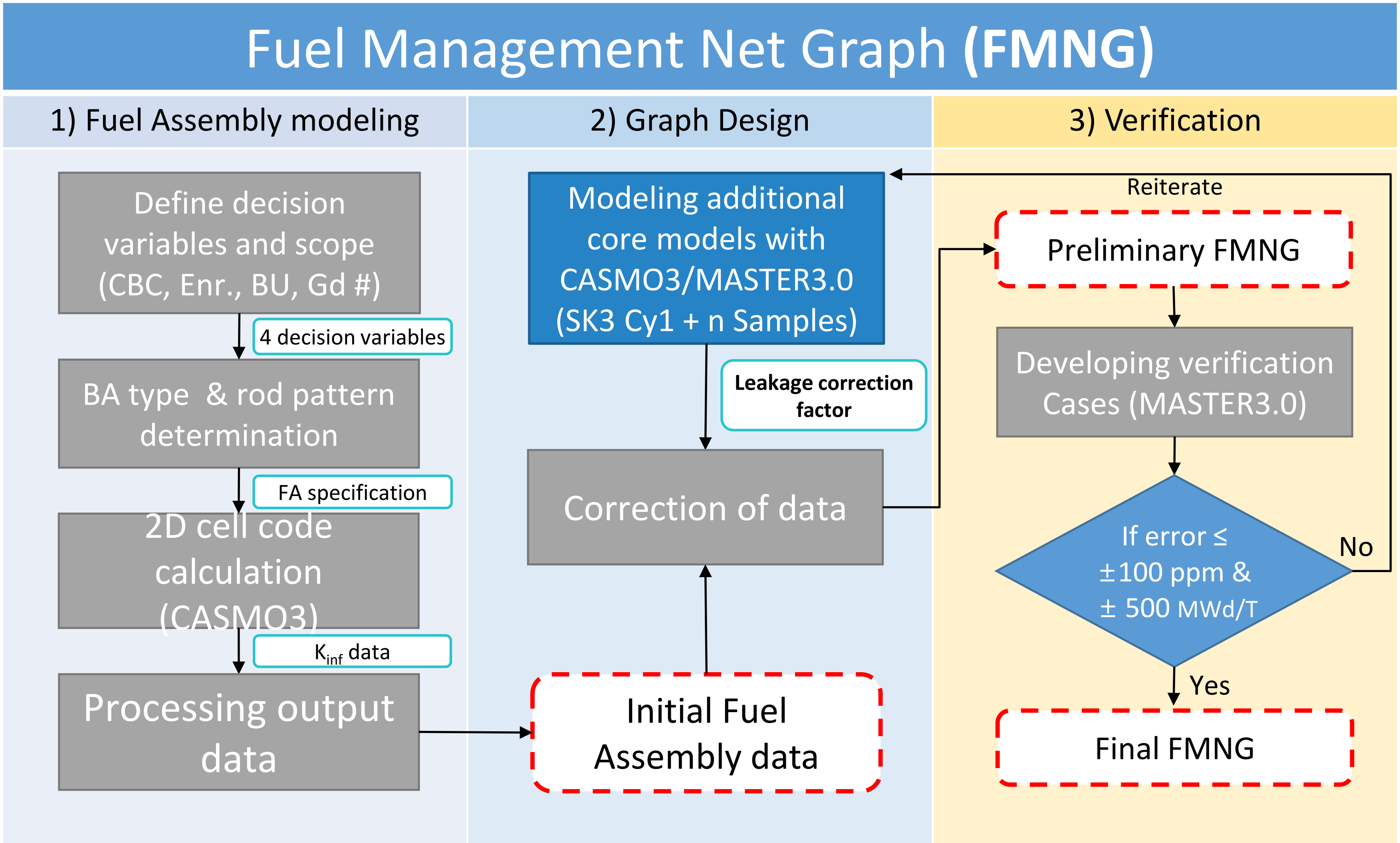




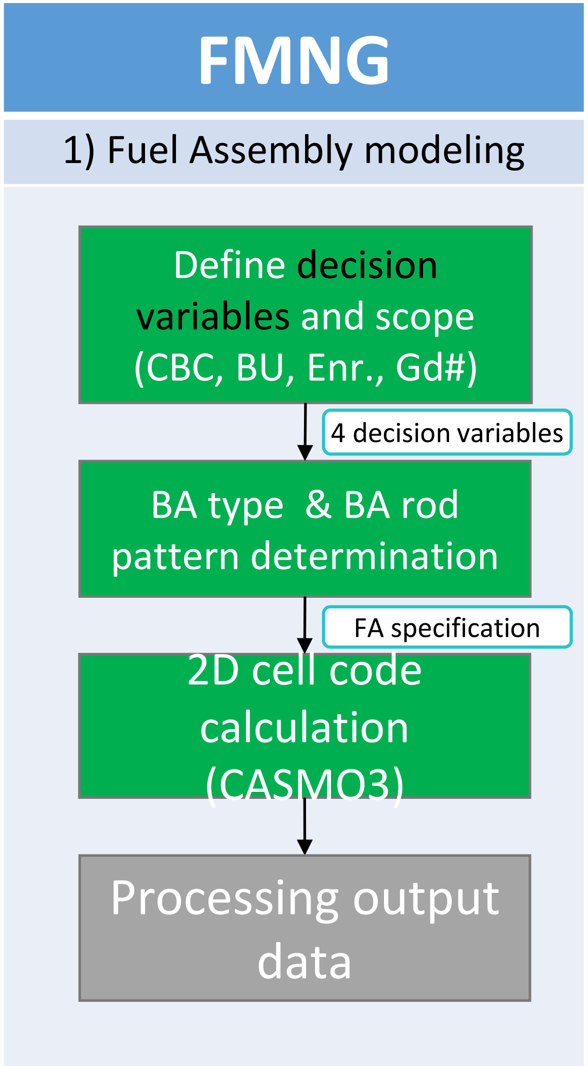
16×16 Fuel Assembly
(PLUS7)

Nuclear Data	Quantity
No. of Fuel Rod	236
Burnable Absorber	Gadolinia
Clad Inner Diameter (cm)	0.836
Clad Outer Diameter (cm)	0.950
Grid density [g/cm³]	6.52
Grid Nuclide ID and w/o	Zircaloy-4, 100%
Clad Density [g/cm³]	5.81
Clad Nuclide ID and w/o	Zircaloy-4, 100%
Fuel Rod array square	16×16
Fuel Pellet Diameter (cm)	0.819
Fuel rod pitch (cm)	1.285
Fuel Stack Density [g/cm³]	10.313
Gd Rod Stack Density [g/cm³]	10.060
Fuel Assembly Pitch (cm)	20.777
Power density [W/gU]	38.25

3. Methodology



3.1 Fuel assembly modeling



Four parameters are taken into consideration in constructing the FMNG:

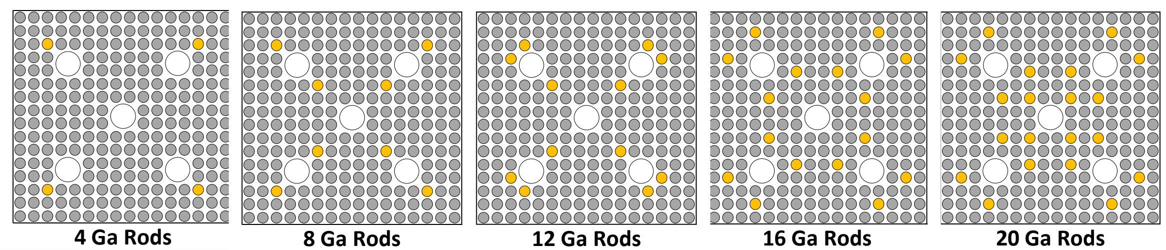
- **Enr.** - Average UO_2 enrichment;
- **Gd#** - Average number of gadolinia rods;

- **CBC** - Critical boron concentration at BOC;
- **BU** - Cycle length.

Input for **fuel assembly population generation:**

- UO_2 enrichment range (1.5% ➔ 4.5%)
- No. of BA rods condition: multiple of 4 (0 ➔ 20 rods)
- The BA rods position is fixed
- Gadolinia **w/o = 8%**

This data will be used as plot points in the FMNG.



3.1 Fuel assembly modeling(continued)

FMNG

1) Fuel Assembly modeling

Define decision variables and scope (CBC, BU, Enr., Gd#)

↓

BA type & rod pattern determination

↓

2D cell code calculation (CASMO3)

↓ K-inf data

Processing output data

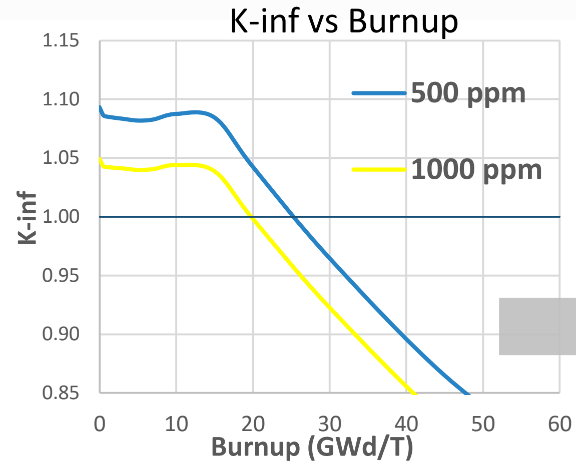


Figure 1

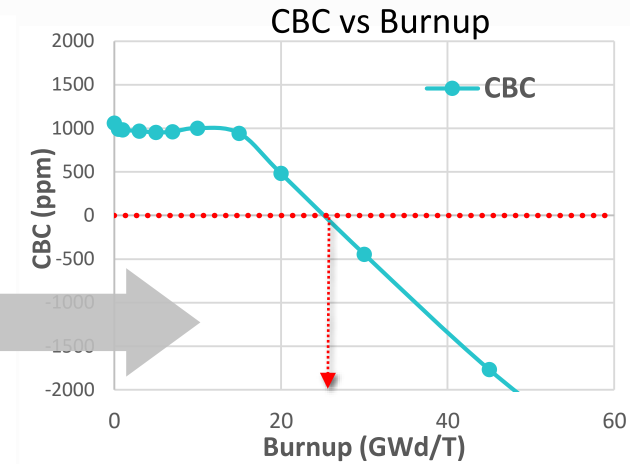
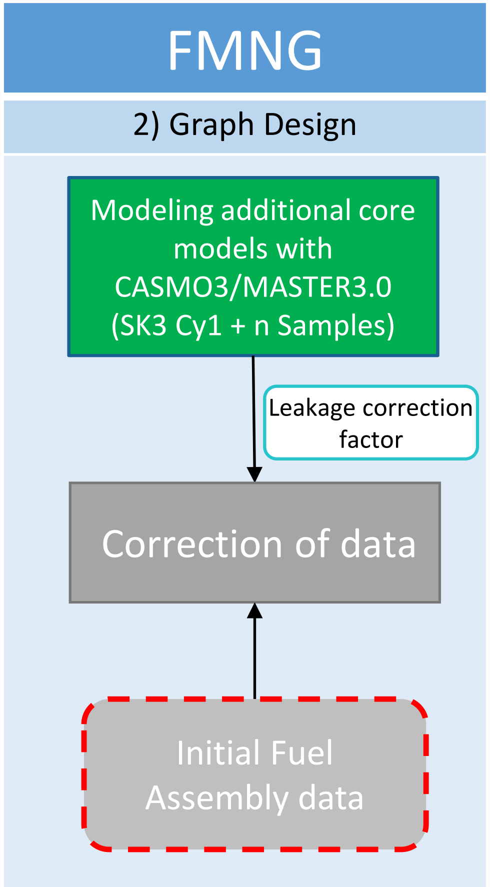


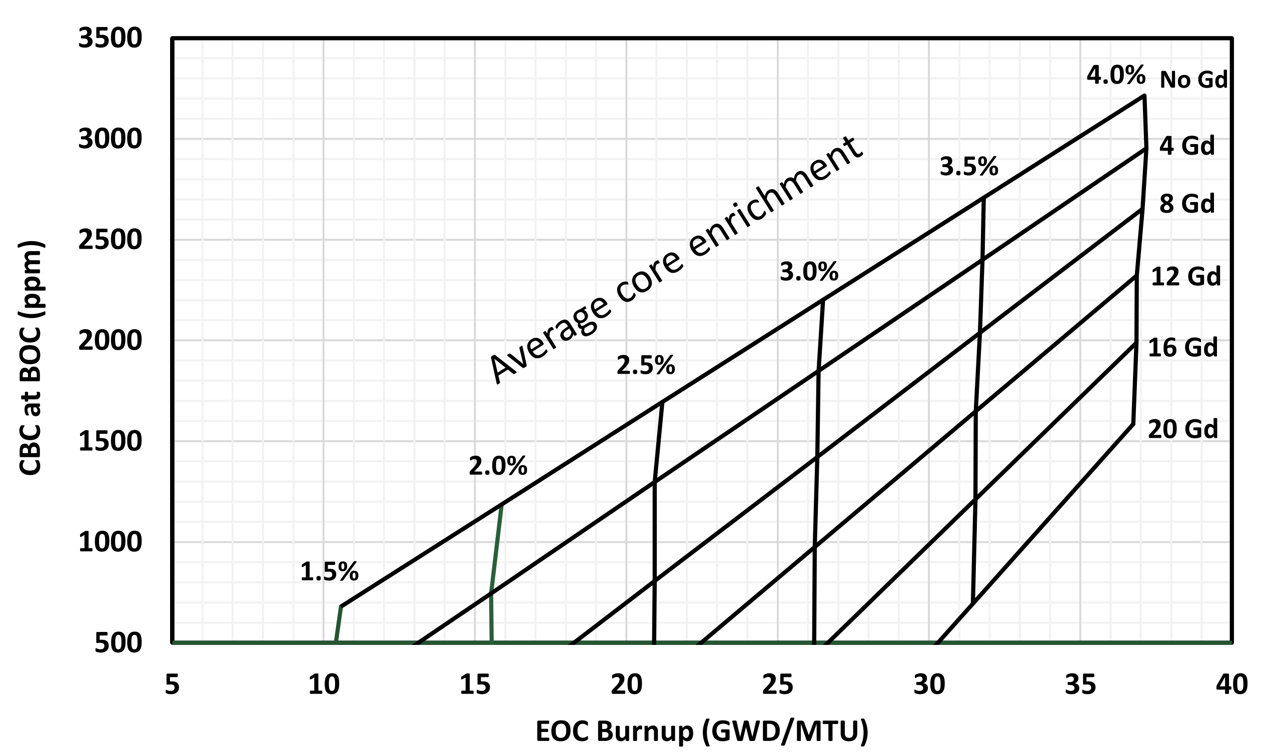
Figure 2

- K-inf according to the burnup in various boron concentration were simulated **to predict CBC at BOC** (Fig.1).
- The k-inf data from all different enrichment and number of BA cases are used for plotting individual CBC curves.
- From the CBC curves, the specific burnup value is determined as **cycle length** (Fig.2).

**Fig1, Fig.2 - Reference example for one fuel assembly*

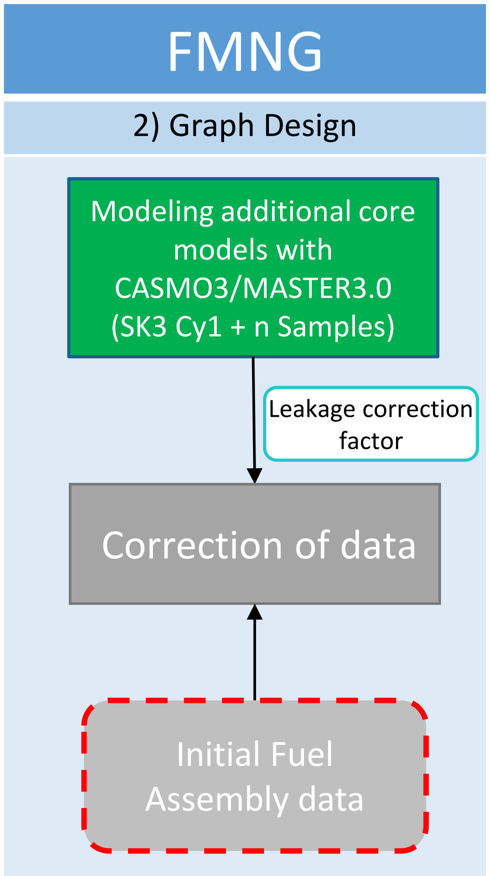
3.2 Graph Design

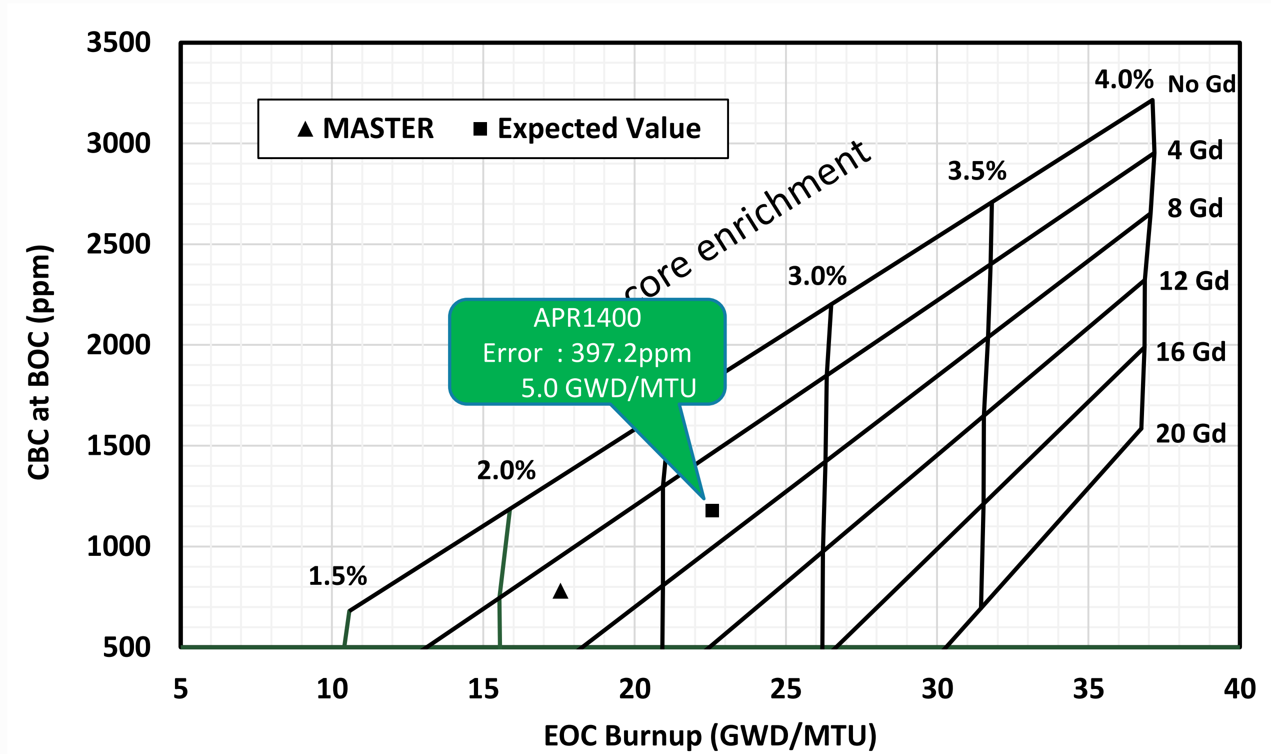




3.2 Graph Design

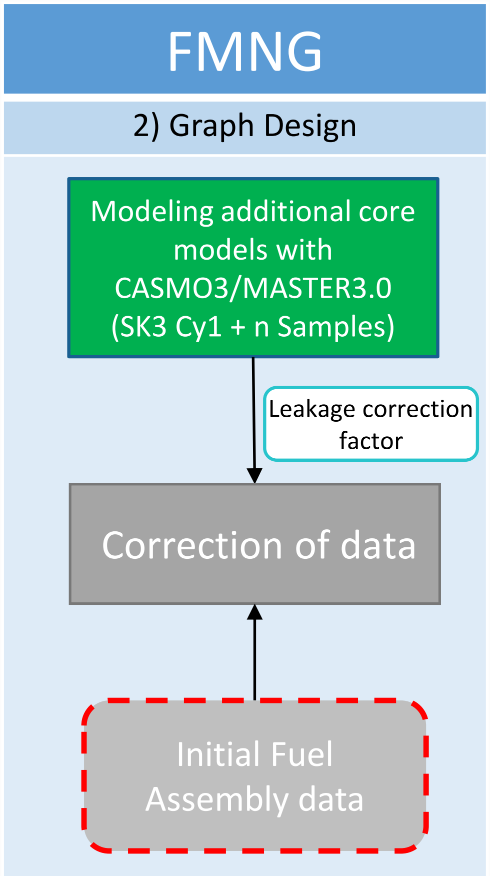
- 3D simulation datapoints are placed on the draft FMNG

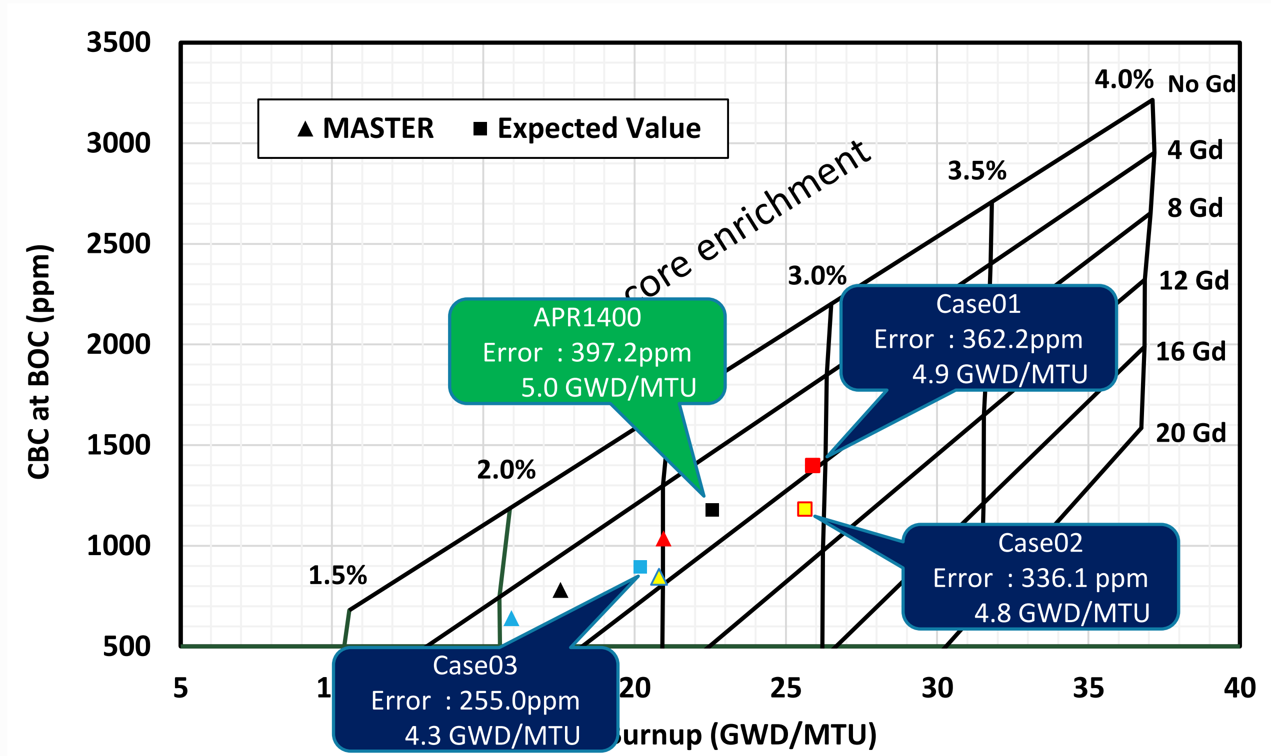




3.2 Graph Design

- 3D simulation datapoints are placed on the draft FMNG
- Accuracy is poor; **why ?**



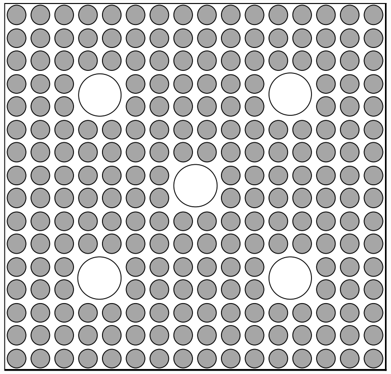


3.2 Graph Design(continued)

- Consideration
  - **Leakage must be taken into account** (apply a correction). 2D Cell code simulates within an infinite boundary medium.
  - Precise **average enrichment** and **average number of BA rods** must be recalculated for each FA considering axial zoning.

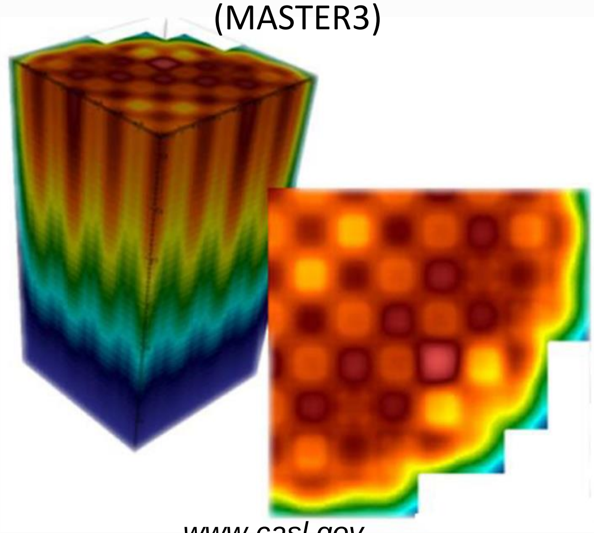
2D Cell code

(CASMO3)



3D Core Model

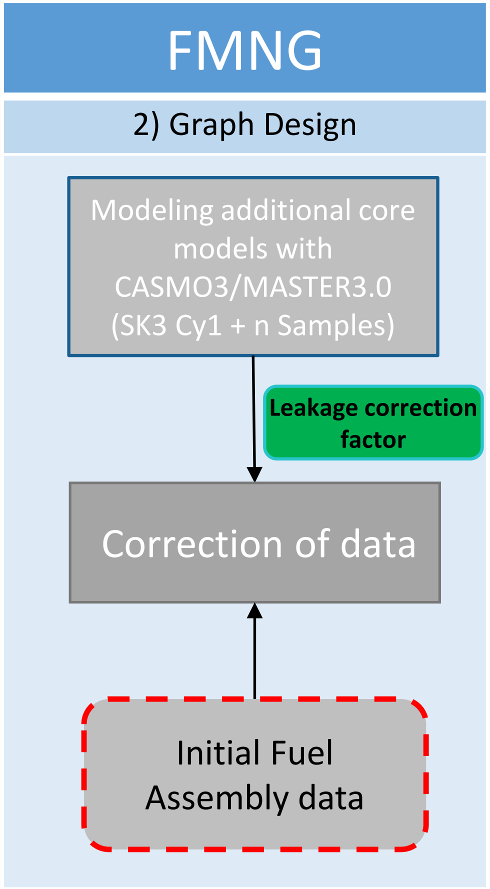
(MASTER3)



www.casl.gov

3.2 Graph Design(continued)

- Leakage correction factor (k_{inf}^{cf})



- Multiple loading pattern search was performed. With same design requirements as SK3, such as PPPF restriction, CBC restriction and approximate cycle length for the given energy requirements.

- The **final leakage correction factor** is determined.

$$k_{inf}^{cf} = \frac{\sum_{case=1}^{n} {}^{average}k_{inf}^{case}}{n}$$

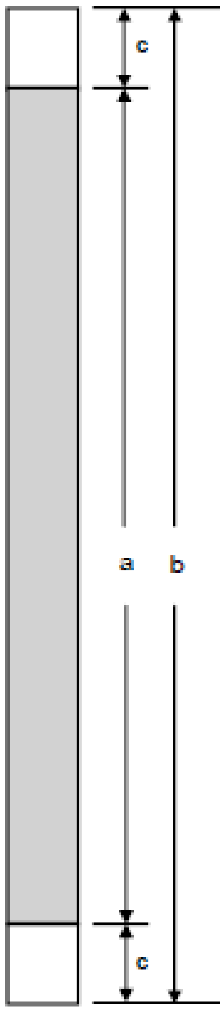
$$k_{inf}^{cf} = 1.04509$$

3.2 Graph Design(continued)

- Average values for 3D core data
  - In a 3D, full core simulation, axial zoning and the different UO_2 enrichment used in the BA rods, significantly **affects average core enrichment**. In order to accurately plot, the axial blanket and the number of BA rods must be considered.
  - The same consideration applies for **the average number of BA rods**. The axial cutback was also taken into consideration.

$$Avg.no.of\ BA = \frac{Total\ number\ of\ BA\ rods}{Total\ no.of\ assemblies}$$

$$Corrected\ avg.no.of\ BA = Avg.no.of\ BA \times (1 - \frac{2 \times Axial\ cutback}{Active\ fuel\ height})$$



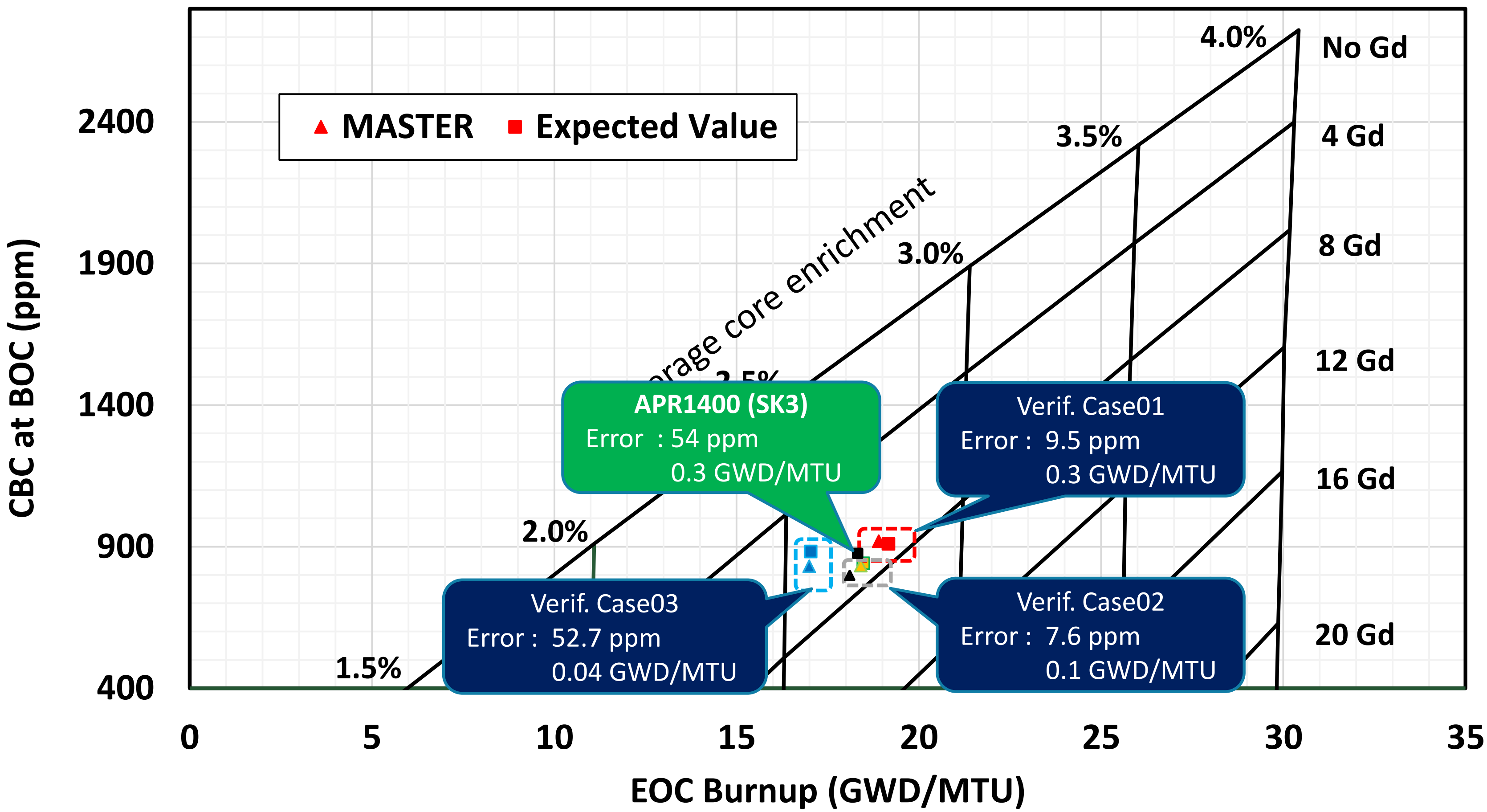
a = 350.52 cm UO_2-Gd_2O_3 Pellets

b = 381.00 cm Active Fuel Height

c = 15.24 cm Axial Cutback

4 Result and Verification

- **Final FMNG**
  - Accuracy is greatly improved, leakage is correctly represented.
  - All results are within the verification criteria criteria (±100 ppm, ±0.5 GWD/MTU).



5.1 Conclusion

- There is a reliable correlation between the considered average parameters (**average core enrichment and average number of BA rods**) and resulting loading pattern **cycle length** and **CBC at BOC.**
- The **FMNG** is a good because:
  - It provides a accurate estimation for giving cycle length and CBC value at BOC, **before performing a full core simulation;**
  - It is **independent of power distribution** of LP;
  - **It saves time** at the initial stage of design.

5.2 Further work

- The FMNG will be coupled with a optimization method (Simplex or Simulated annealing) to directly determine fuel batch wise specifications (fuel zoning, BA pattern, no of specific assemblies), in order determine a better LP.

Thank you for your attention !