DEVELOPMENT OF A FUEL BURN-UP CALCULATION MODEL IN A REDUCED REACTOR GEOMETRY

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What we have done?

- Batan in-core fuel management code (Batan-FUEL) has been developed using a 2-D few group neutron diffusion method
- Batan-FUEL is extensively used for routine in-core fuel management and for oxide to silicide core conversion program of the multipurpose reactor of G.A. Siwabessy (RSG-GAS).

Why we had to ?

- For routine in-core fuel management, direct burn-up calculations in 3-D reactor geometry are impractical and require expensive computational resources (CPU time)
- On the other hand, effect of control rods position history on fuel burn-up can not be neglected

- Burn-up calculation model in a reduced geometry (2-D) is proposed

How we did ?

- Consideration
  - Control rods are operated in bank-mode during normal reactor operation
  - Fuel reshuffling pattern for a typical working core (TWC) does not change
- Hypothesis
  - Effect of control rods position history on burn-up can be modeled by interpolating fully inserted and fully withdrawn data
- Task
  - An optimal interpolation function has to be sought

Theory (1)

- **Exact 3-D Burn-up Calculation Model**

$$B_m^{t+\Delta t} = B_m^t + \frac{1}{W_m^0} \int_t^{t+\Delta t} Q_m d\tau \qquad (1)$$

$$Q_m \equiv \int_{V \in V_m} q(x,y,z) dV \qquad (2)$$

$$= \gamma \int_{V \in V_m} \Sigma_f (x,y,z) \Phi(x,y,z) dV$$

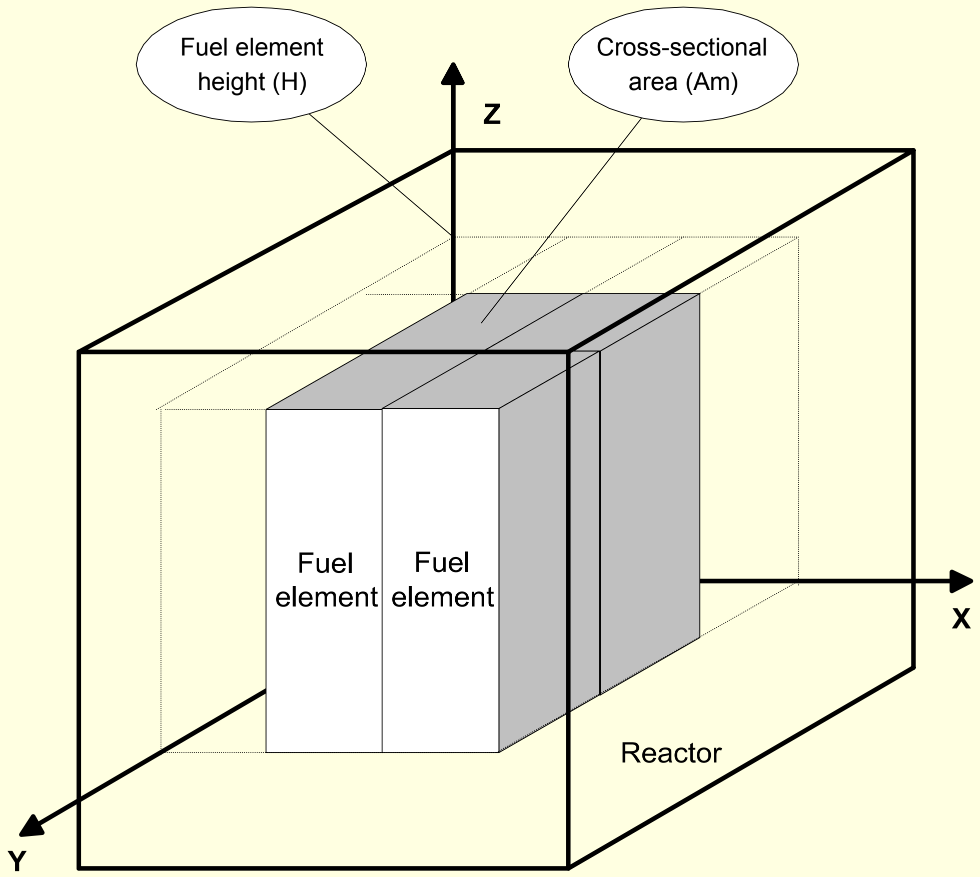
$$\mathbf{M\Phi} = \frac{1}{k_{eff}} \mathbf{F\Phi} \qquad (3)$$

$$P = \gamma \int_{V \in V_{CORE}} \Sigma_f (x,y,z) \Phi(x,y,z) dV = \sum_{m=1}^{M} Q_m$$

- 3-D neutron flux distribution can be produced directly from the 3-D solution of Eq.(3)
- Burn-up equation, Eq.(1), can be solved without any approximation

Theory (2)

- **Reduced 2-D Burn-up Calculation Model**



Core geometry:

1. All fuel elements have same height, H cm
2. The zero point of z-axis at the core bottom

Theory (3)

The radial power peaking factor is defined as:

$$F_m \equiv \frac{1}{Q_{AVE} V_m} \int_{A \in A_m} dA \int_{z \in (0,H)} q(x,y,z)dz = \frac{1}{Q_{AVE} A_m} \int_{A \in A_m} q_z(x,y)dA \quad \text{for } m = 1,\ldots,M \qquad (4)$$

where the 2-D power density distribution:

$$q_z(x,y) \equiv \int_{z \in (0,H)} q(x,y,z)dz \qquad (5)$$

and power generation by *m*-th fuel

$$Q_m = F_m Q_{AVE} \quad \text{for } m = 1,\ldots,M \qquad (6)$$

Theory (4)

Assumptions

$$F_m^{2D}(r=0) \approx F_m^{3D}(r=0) \quad \text{for} \;\; m = 1,\dots,M$$

$$F_m^{2D}(r=H) \approx F_m^{3D}(r=H) \;\; \text{for} \;\; m = 1,\dots,M$$

Simplification from
3-D to 2-D

$$F_m^{2D} = g_m(r) \;\; \text{for} \;\; r \in (0,H) \quad \text{and} \quad m = 1,\dots,M \qquad (7)$$

where g is interpolation function

Interpolation Functions (1)

- Linear function

$$g_m(r) = g_m(0) + \left\{\frac{r}{H}\right\}\{g_m(H) - g_m(0)\}$$

- S-shape function

$$g_m(r) = g_m(0) + \left\{\frac{r}{H} - \frac{C}{2\pi}\sin\left(\frac{2\pi r}{H}\right)\right\}\{g_m(H) - g_m(0)\}$$

- Exponential function with one coefficient C

$$g_m(r) = g_m(0)\left\{1 - \left(\frac{r}{H}\right)^C\right\} + g_m(H)\left(\frac{r}{H}\right)^C$$

Interpolation Functions (2)

- Linear combination of S-shape and Exponential funtions

$$g_m(r) = w \cdot f_m^1(r) + (1-w) \cdot f_m^2(r)$$

where

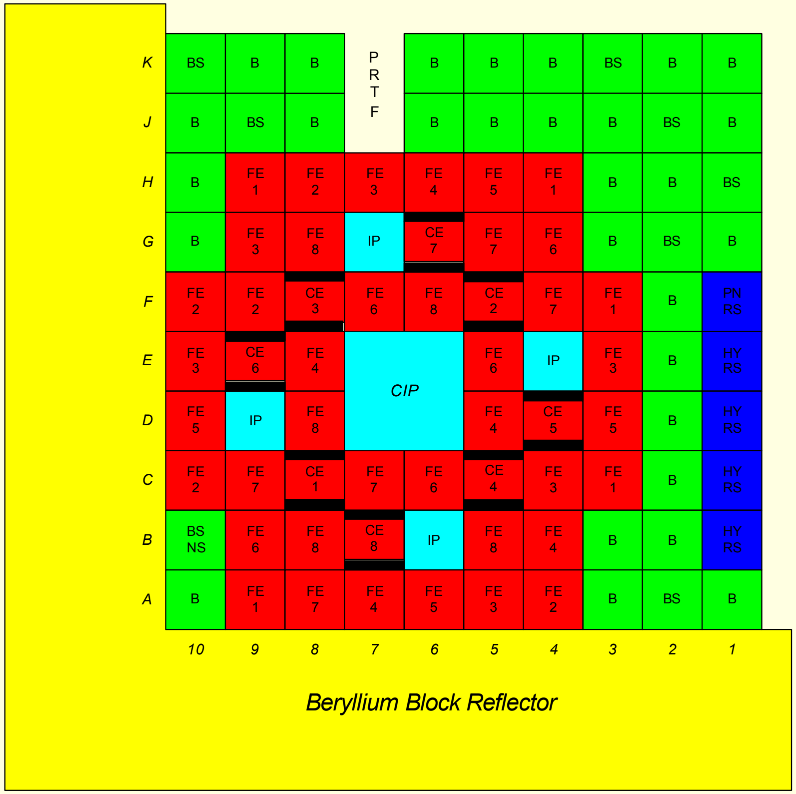
$$f_m^1(r) = f_m^1(0) + \left\{ \frac{r}{H} - \frac{A}{2\pi} \sin\left(\frac{2\pi r}{H} \right) \right\} \left\{ f_m^1(H) - f_m^1(0) \right\}$$

$$f_m^2(r) = f_m^2(0) \left\{ 1 - \left(\frac{r}{H} \right)^B \right\} + f_m^2(H) \left(\frac{r}{H} \right)^B$$

Interpolation Functions (3)

- Advantages of the proposed interpolation functions:
  - The boundary points: the radial power peaking factors at fully withdrawn and fully inserted can be derived from 2-D calculation results
  - The interpolation function do not depend on fuel element index, *m*
  - The interpolation function valid over a wide range core configuration and fuel composition

Application



Note : FE = Fuel Element, CE = Control Element, BE = Be Reflector Element, BS = Be Reflector Element with plug, IP = Irradiation Position, CIP = Central Irradiation Position, PNRS = Pneumatic Rabbit System, HYRS = Hydraulic Rabbit System (burn-up classes are in the second rows)

RSG-GAS

- 8 control rod absorber
- 40 standard fuel element
- 8 control fuel element
- active core height : 60 cm

Oxide and Silicide Typical Working Cores

Results

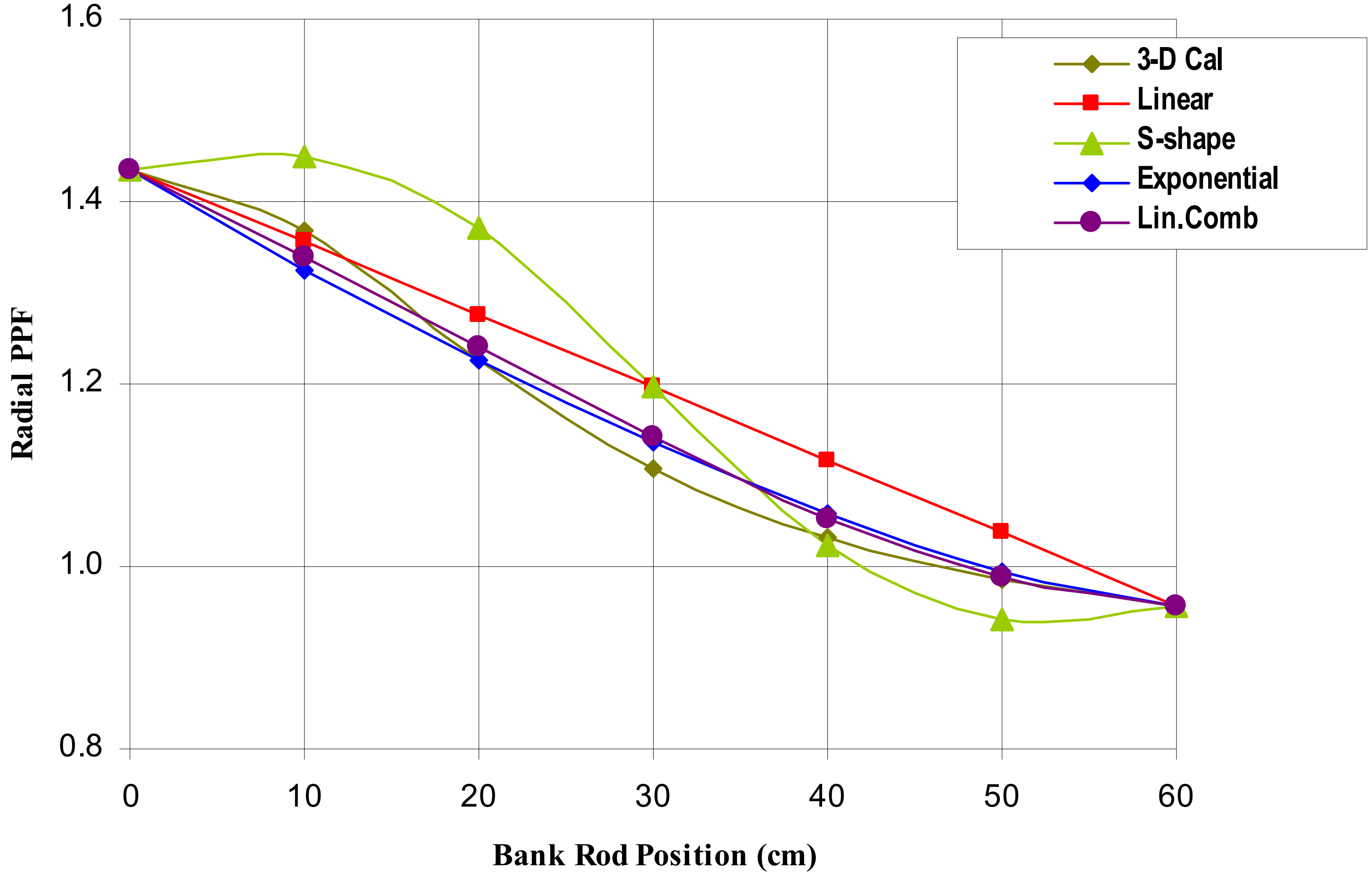
Typical Working Core	Interpolation Function							
	Linear		S-shape		Exponential		Lin. Comb.	
	E(%)	C	E(%)	C	E(%)	C	E(%)	C
Oxide	1.117	-	1.613	1.425	0.479	1.425	0.401	1.425
Silicide	1.107	-	1.535	1.400	0.528	1.400	0.436	1.400

E: Least Squared Error

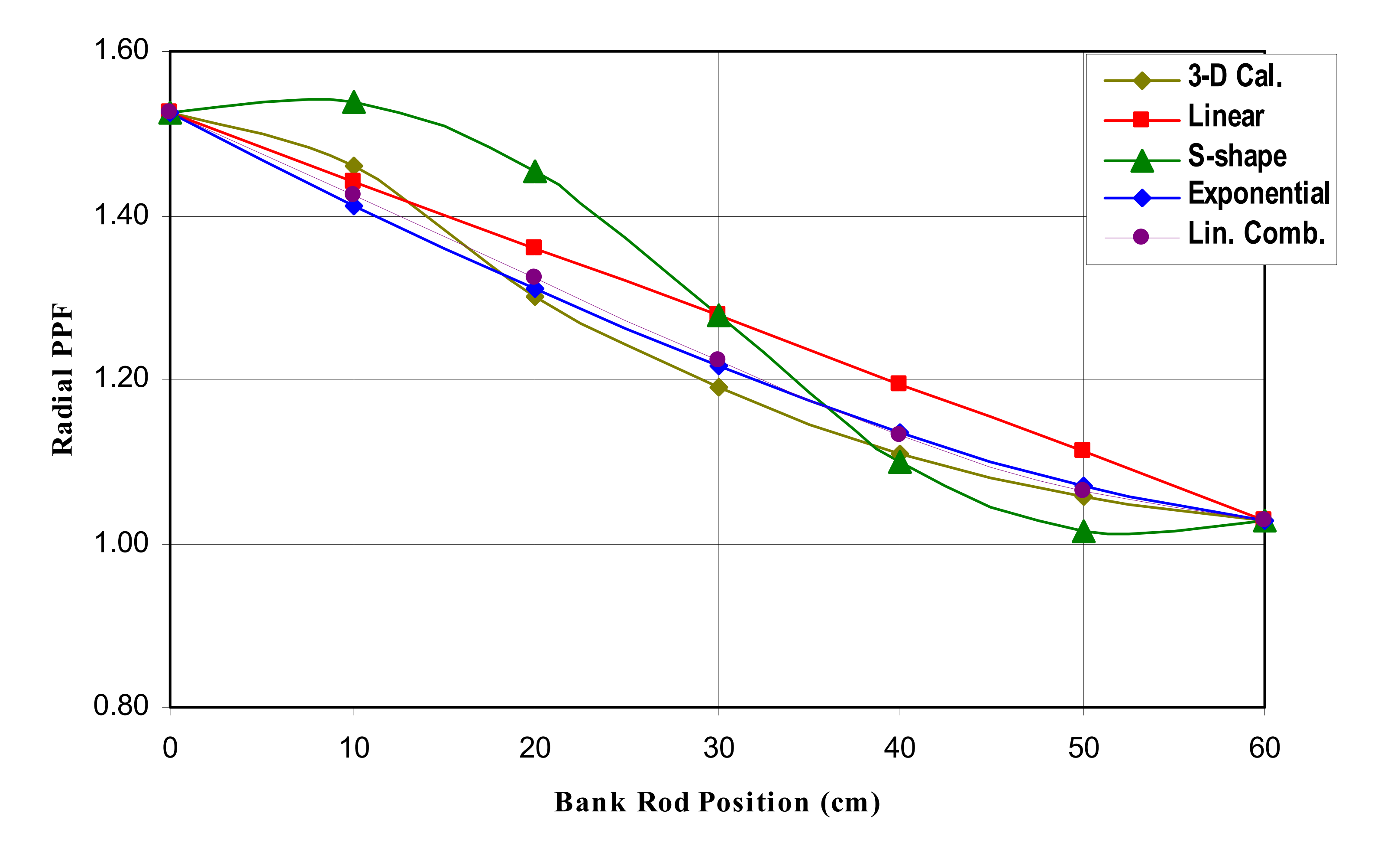
C: Optimal coefficient

$$E = \frac{1}{M} \sum_{m=1}^{M} \sum_{i=1}^{I} \left(g_m(r_i) - F_m^{3D}(r_i) \right)^2$$

The 2D-calculated radial PPF as a function of control rod bank position at H-9 core grid position for oxide core



The 2D-calculated radial PPF as a function of control rod bank position at H-9 core grid position for silicide core



CONCLUSIONS

- The newly proposed fuel burn-up calculation model in a reduced geometry (2D) shows a good agreement with the exact 3D model
- The linear combination of an S-shape and exponential functions gives the best agreement for both oxide and silicide typical working cores of RSG GAS