AECL EACL

RFSP Model

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Canada

AECL Atomic Energy of Canada Limited

EACL Énergie atomique du Canada limitée

Static Two-Energy-Group Neutron Diffusion Equation for Eigenvalue Problems

Two-group equation solved by RFSP:

$$-\nabla \bullet D_1(\vec{r})\nabla\Phi_1(\vec{r}) + \left(\Sigma_{a1}(\vec{r}) + \Sigma_{12}(\vec{r})\right)\Phi_1(\vec{r}) - \Sigma_{21}(\vec{r})\Phi_2(\vec{r}) - \frac{1}{k_{eff}}\left(\nu\Sigma_{f1}(\vec{r})\Phi_1(\vec{r}) + \nu\Sigma_{f2}(\vec{r})\Phi_2(\vec{r})\right) = 0$$

$$-\nabla \bullet D_2(\vec{r})\nabla\Phi_2(\vec{r}) + \left(\Sigma_{a2}(\vec{r}) + \Sigma_{21}(\vec{r})\right)\Phi_2(\vec{r}) - \Sigma_{12}(\vec{r})\Phi_1(\vec{r}) = 0$$

Static Two-Energy-Group Neutron Diffusion Equation for Eigenvalue Problems (con't)

where, at position $\vec{r}$

$\Phi_1(\vec{r})$ and $\Phi_2(\vec{r})$ are the group-1 and group-2 neutron fluxes respectively,

$\Sigma_{a1}(\vec{r})$ is the group-1 (fast) absorption cross section,

$\Sigma_{a2}(\vec{r})$ is the group-2 (thermal) absorption cross section,

$\nu\Sigma_{f1}(\vec{r})$ is the production cross section for the fast group,

$\nu\Sigma_{f2}(\vec{r})$ is the production cross section for the thermal group,

$\Sigma_{12}(\vec{r})$ is the cross section for transfer from the fast group to the thermal group (also called downscatter),

$\Sigma_{21}(\vec{r})$ is the cross section for transfer from the thermal group to the fast group (also called upscatter),

$D_1(\vec{r})$ is the group-1 (fast) diffusion coefficient,

$D_2(\vec{r})$ is the group-2 (thermal) diffusion coefficient, and

k_{eff} is the reactor multiplication constant and is the inverse of the eigenvalue

Static Two-Energy-Group Neutron Diffusion Equation for Eigenvalue Problems (con't)

The diffusion coefficients D_g are related to the transport cross sections $\sum_{tr,g}$ (g = 1, 2) by:

$$D_g(\vec{r}) = \frac{1}{3\Sigma_{tr,g}(\vec{r})} \qquad g=1,2$$

where $\Sigma_{tr,g}(\vec{r}) = \Sigma_{12}(\vec{r})(1-\mu_{o,g})$ and $(1-\mu_{o,g})$ is the correction to the scattering cross-section to take account of non-isotropic scattering.

Data Prerequisite to Solve Diffusion Equation

- ***What*** **is in the reactor**
- ***Where*** **it is**
- ***In what state*** **it is (e.g.,** ***irradiation*****)**

<u>Geometry</u>

Length and radius of calandria, radius of notch

Reflector thickness

Lattice pitch, bundle length

Mesh lines used in finite-difference model

Distinction between ***mesh array*** **(for flux calculation) and** ***lattice array*** **(defining fuel bundles)**

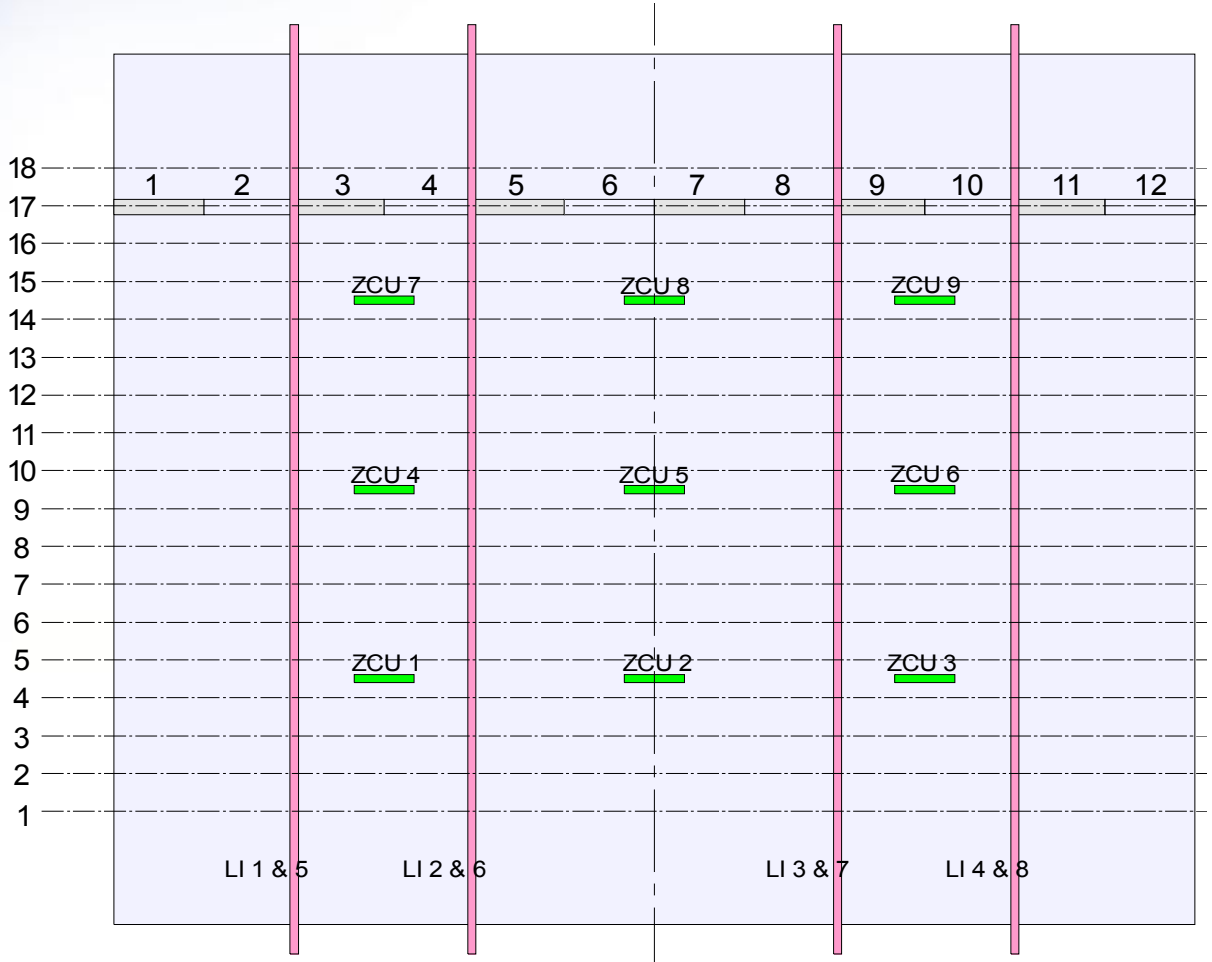
Axial and radial extrapolation lengths

This data entered via *DATA GEOMETRY cards.

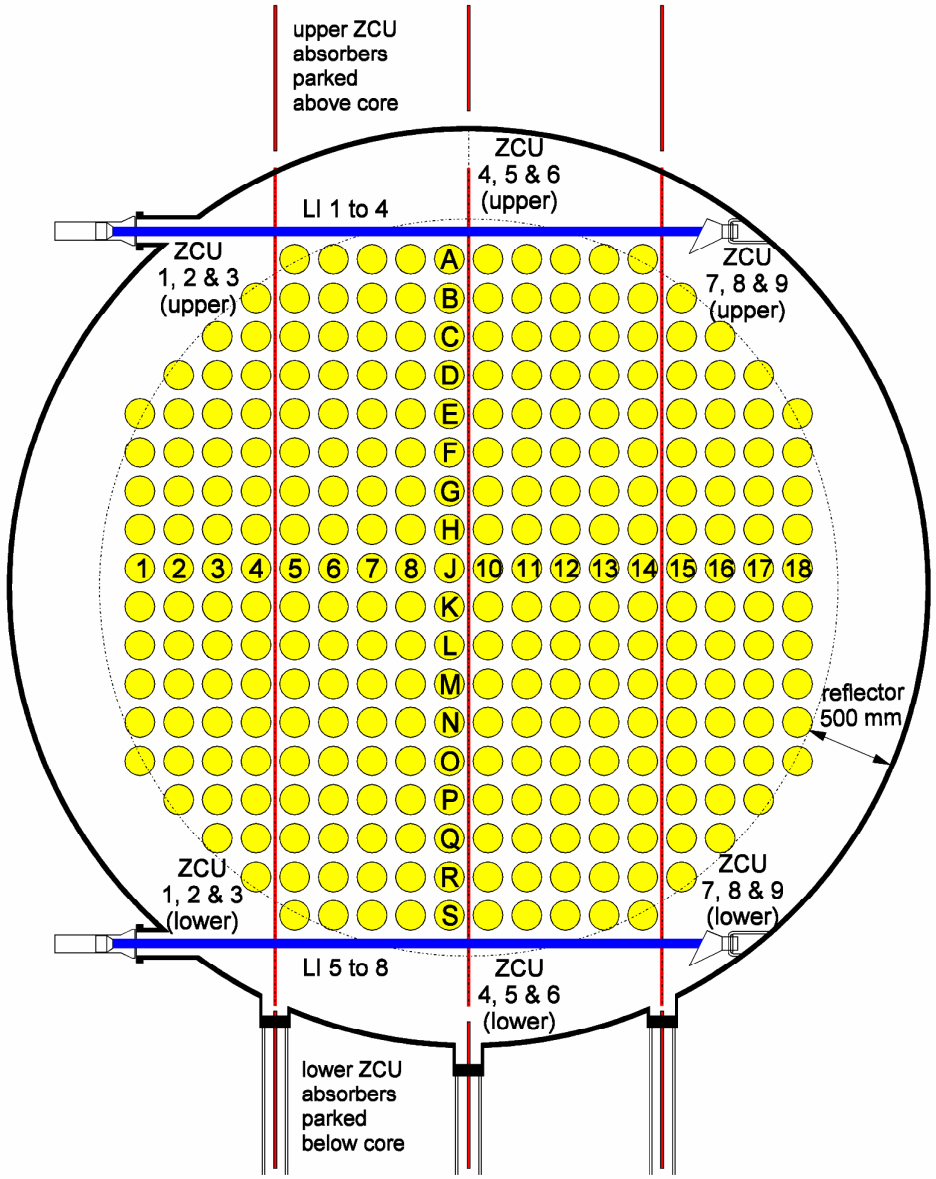
Mesh Spacing

- The finite-difference model is a collection of rectangular parallelepipeds, defined by the *mesh lines*. The RFSP user defines the mesh lines in the model.
- By definition, the nuclear properties are *uniform* over each parallelepiped (and the flux is calculated at its mid-point).
- However, the properties are not *directly* defined over the parallelepipeds. They are defined over:
  - lattice cells (for lattice properties)
  - defined volume of influence (for reactivity devices)

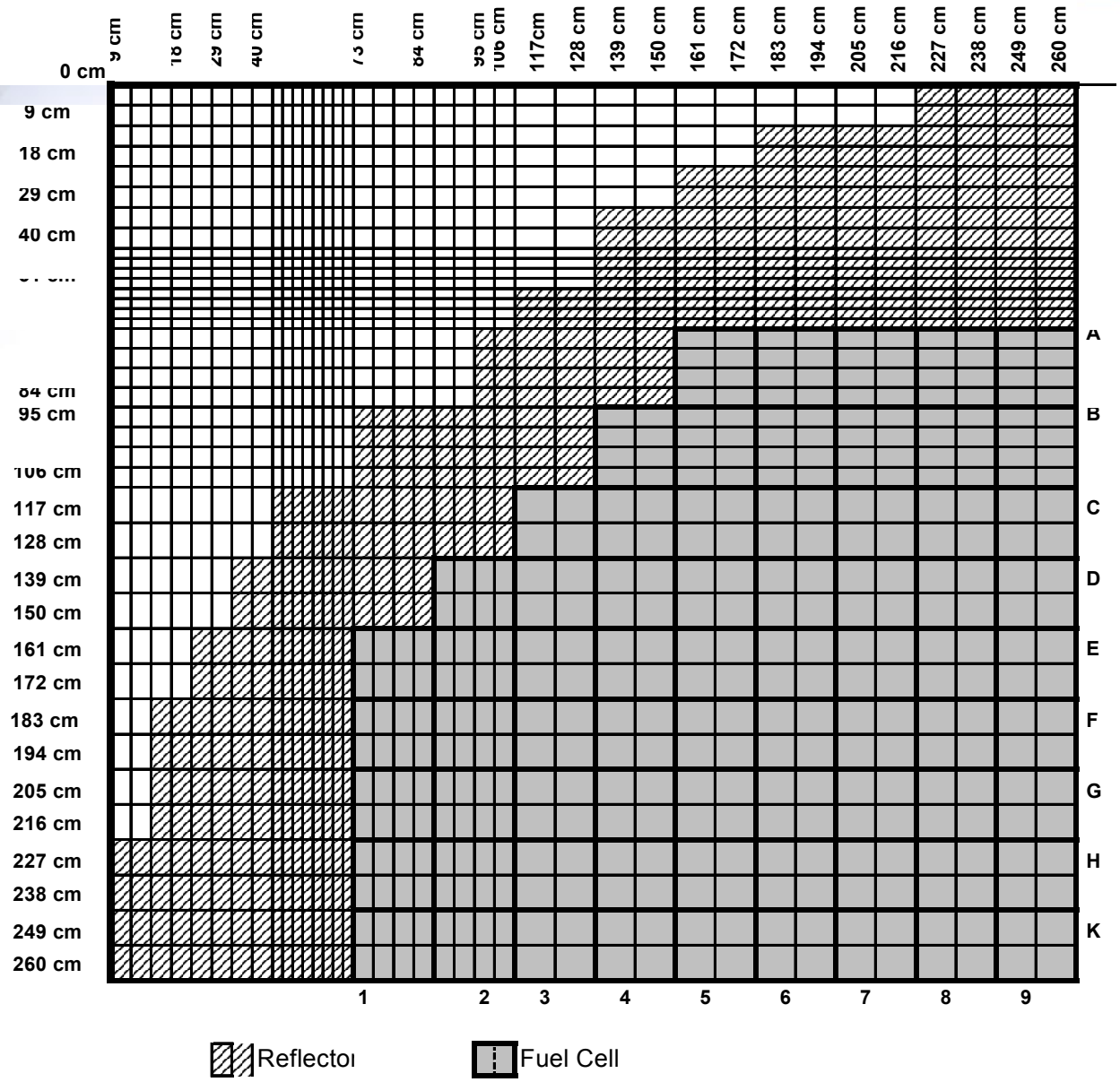
Top View of ACR Model

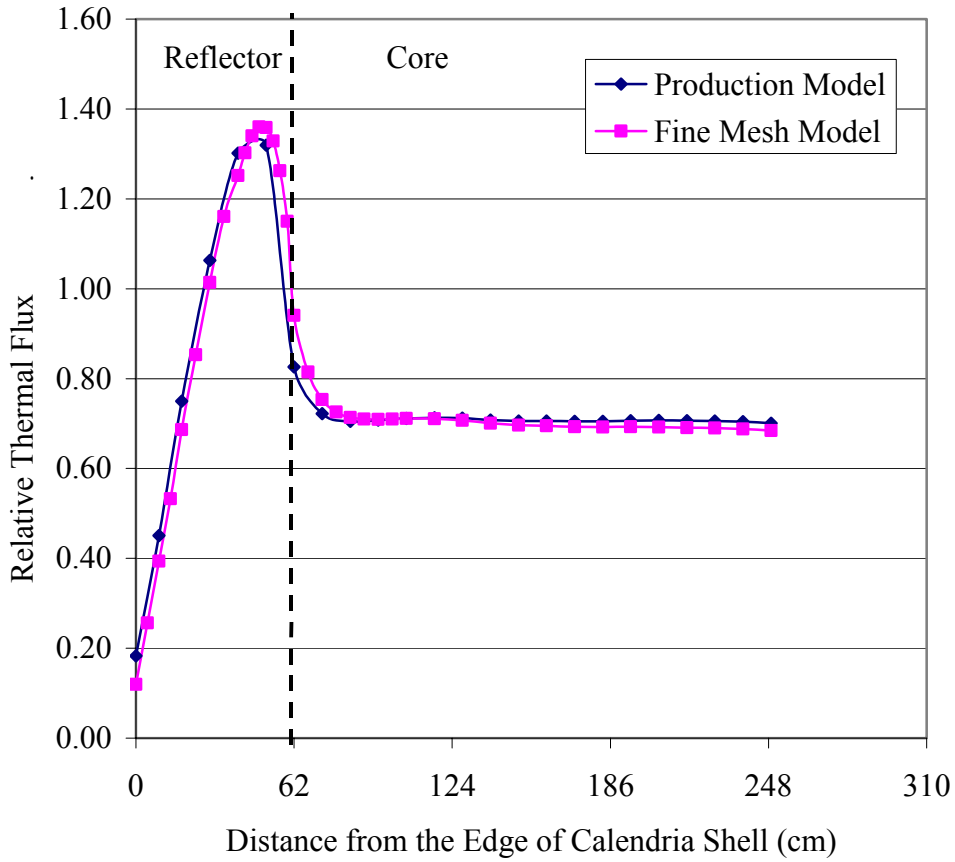


ZCU= Zone Control Unit
LI = Liquid Poison Injection Tubes



ACR-700 Reactor Core
284 Fuel Channels
220 mm Lattice Pitch


0 cm
9 cm
18 cm
29 cm
40 cm
84 cm
95 cm
106 cm
117 cm
128 cm
139 cm
150 cm
161 cm
172 cm
183 cm
194 cm
205 cm
216 cm
227 cm
238 cm
249 cm
260 cm
A
B
C
D
E
F
G
H
K
1
2
3
4
5
6
7
8
9
Reflector
Fuel Cell


Reflector
Core
Production Model
Fine Mesh Model
Relative Thermal Flux
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
62
124
186
248
310
Distance from the Edge of Calendria Shell (cm)

Lattice Properties Overview

- **Uniform Parameter – Simplest Method**
  - lattice properties are tabulated as functions of fuel burnup (or irradiation) only
  - assume effective core-average conditions for each fuel bundle
  - cannot account for local-parameter effects such as distributed power, xenon, coolant temperature, etc.
  - not suitable for accurate core-tracking and xenon transient simulations
  - Used for time-average and some static calculations (*TIME-AVER, *INSTANTAN and sometimes *SIMULATE)

Lattice Properties Overview Cont…..

- Grid Based or Macro-Depletion Method
  - lattice properties are specified as functions of fuel burnup (or irradiation) and of other local parameters
  - macroscopic cross sections are generated beforehand at various assumed operating conditions
  - Interpolation is performed for each fuel bundle to generate local-parameter-dependent macroscopic cross sections
  - does not take into account the dependence of the cross sections on a bundle's history
  - Used in kinetics module of RFSP (*CERBERUS)

Lattice Properties Overview Cont…..

- Micro-Depletion Method
  - as simple as the macro-depletion model
  - but addresses both:
    - the microscopic cross section of a nuclide (independent of history) and
    - its number density, which depends on the depletion history
  - Used in the *SIMULATE module for core tracking calculations

Lattice Properties Overview Cont…..

- Direct use of WIMS – Most Rigorous Method
  - history-based local-parameter method
  - lattice code is coupled directly with the core-analysis code, and the lattice calculations are performed for each bundle at each time step
  - impractical for routine calculations at this time
  - Some work has been performed to demonstrate feasibility of parallel processing techniques using PVM or MPI.

Reactivity Devices

- Device properties given as incremental cross-sections over some volume of influence (usually lattice pitch x length x bundle length)
- Calculated by supercell code (e.g., DRAGON) and added to lattice cross sections over volume of influence

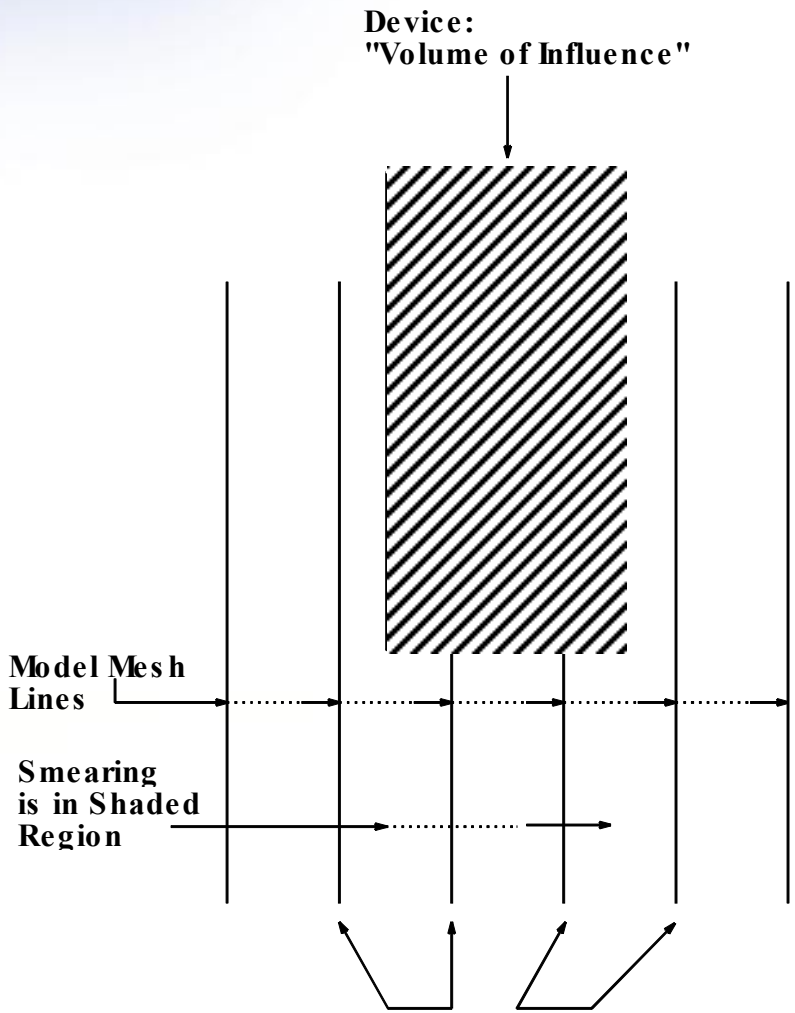
Property Smearing

- If the boundaries of the lattice cells and/or of the device volumes of influence do not coincide with mesh lines, the properties will be smeared to the *next* (outwardly) mesh line. The smearing involves “diluting” the cross-sections in inverse proportion to volume.

Smearing is not recommended because:

- It denies the volume over which the cell code or device code “wanted” to act especially in terms of absorption, a wider volume of action increases the absorption (even in the presence of dilution); e.g., reactivity worth of shutoff rods is artificially enhanced - non conservative.

Moral of Story: ensure your model has no smearing



Mesh Lines to Which Device Properties are Smeared