POWDERPUFS-V

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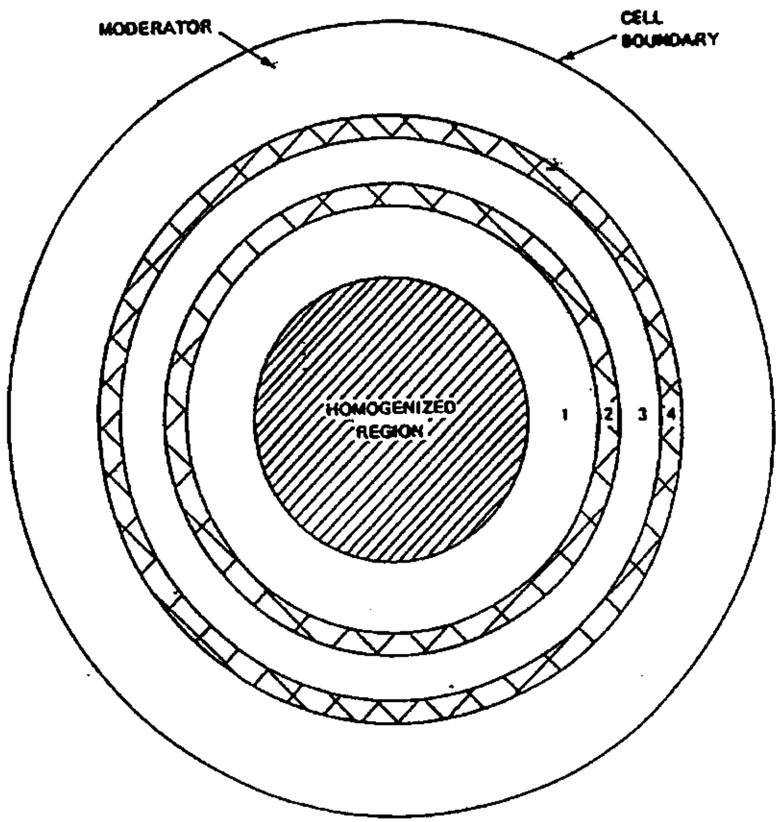
Powderpufs-V

- Cell code: calculates cross-sections for basic lattice cells
- Written specifically for CANDU lattices
  - D_20 moderator
  - U isotopic close to that of natural fuel
  - no appreciable Pu concentration
- Based on Westcott formulation
- Simple recipes and formulas which reproduce experimental results
- Incorporated within RFSP
- Works with simplified annular geometry of lattice cell



REGION:

1	COOLANT ANNULUS
2	PRESSURE TUBE
3	AIR-GAP
4	CALANDRIA TUBE

Westcott Formulation

Neutron spectrum is well thermalized. Most neutrons are in thermal range.

Write spectrum as a Maxwellian distribution with a 1/*E* epithermal tail:

$$n(\nu)=N(1-f)\rho_m(\nu)+N\rho_e(\upsilon)$$

≤

where:	N	=	total neutron density
	f	=	fraction of total neutron density in epithermal spectrum (must be small a few per cent)
	$\rho_m(\nu)$	=	Maxwellian spectrum
		=	$\frac{4}{\sqrt{\pi}}\frac{v^2}{v_T^3}e^{-(v/v_T)^2}$
	v_T	=	velocity of neutron with energy kT_n
	T_n	=	neutron temperature
	$\rho_e(\nu)$	=	epithermal spectrum (tail)
			$v_T\sqrt{\mu}\frac{\Delta(v)}{v^2}$

Wescott Formulation (con't)

μ	=	3.681 (Westcott convention)
$\Delta(\nu)$	=	0, for small energies ($E <\ kT$),
	=	1, for large energies ($E >\ kT$)

Westcott Formalism (con't)

The Westcott formalism leads to the following form for the total reaction rate:

$$\text{Reaction Rate} = N v_0 \hat{\sigma}$$

where:

N	=	total neutron density
v_0	=	2200 m/s
$\hat{\sigma}$	=	microscopic Westcott cross-section, which can be written as: $\hat{\sigma} = \sigma_0 (g + rs)$

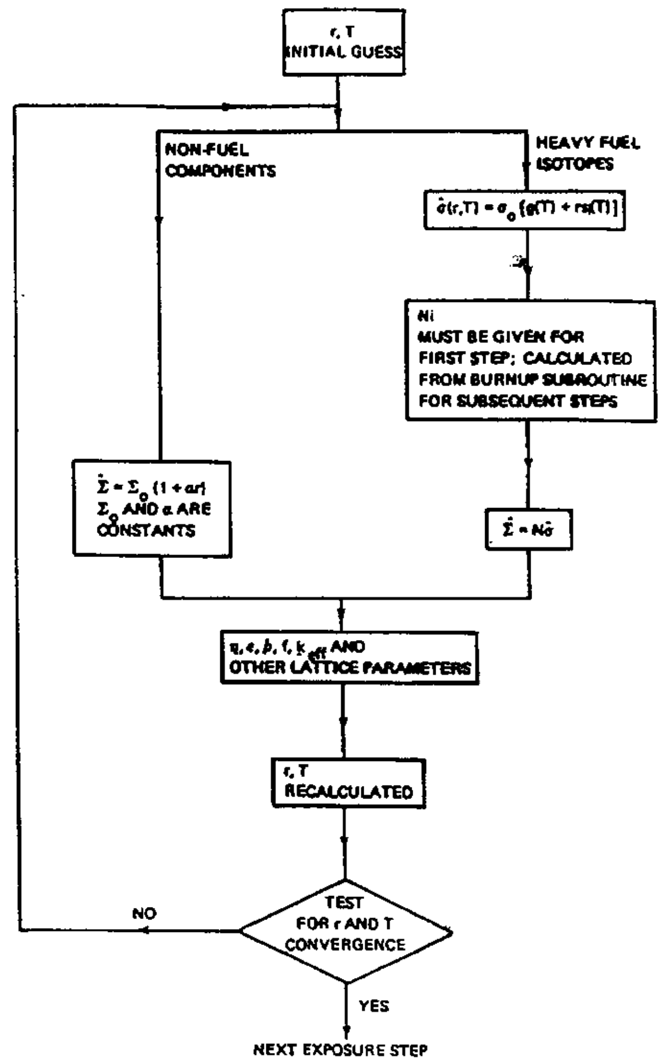
and,

σ_0	=	cross-section at 2200 m/s
r	=	epithermal index ("Westcott r") related to f
	=	$\frac{1}{4} f \sqrt{\pi\mu}$
g, s	=	microscopic quantities dependent on the nuclide (for a pure $1/v$ absorber, $g = 1$ and $s = 0$)

PPV Continued...

T_n and r

- All lattice properties are thus derived from the Westcott r and the neutron temperature (in fuel T_{nf}, annulus T_{na}, and moderator T_{nm} regions).
- T_n and r are calculated internally.
- This is an iterative calculation because r and T_n depend on the four-factor quantities, which are functions of r and T_n.


r, T
INITIAL GUESS
NON-FUEL
COMPONENTS
HEAVY FUEL
ISOTOPES
MUST BE GIVEN FOR
FIRST STEP; CALCULATED
FROM BURNUP SUBROUTINE
FOR SUBSEQUENT STEPS
AND α ARE
CONSTANTS
OTHER LATTICE PARAMETERS
r, T
RECALCULATED
TEST
FOR r AND T
CONVERGENCE
NO
YES
NEXT EXPOSURE STEP

PPV Continued...

Four-Factor Formula

$k_\infty = \varepsilon p f \eta$

k_∞ = lattice (infinite) multiplication constant

ε = fast-fission factor

p = resonance-escape probability

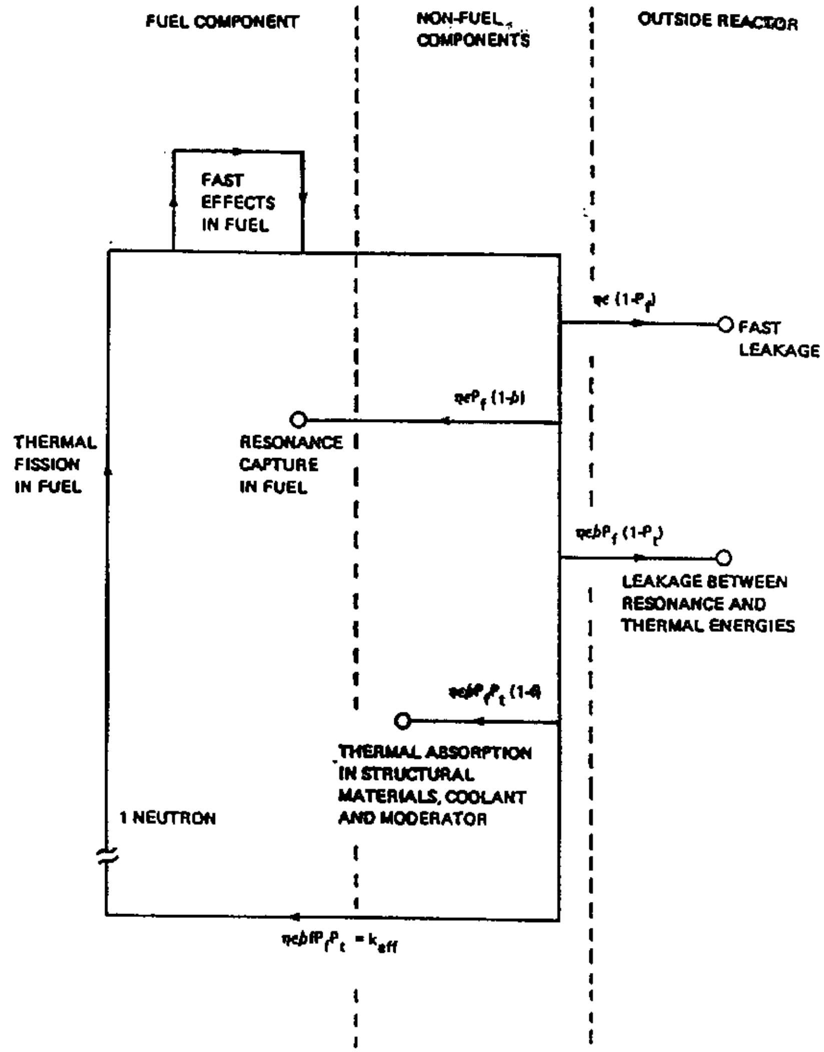
f = fuel utilization

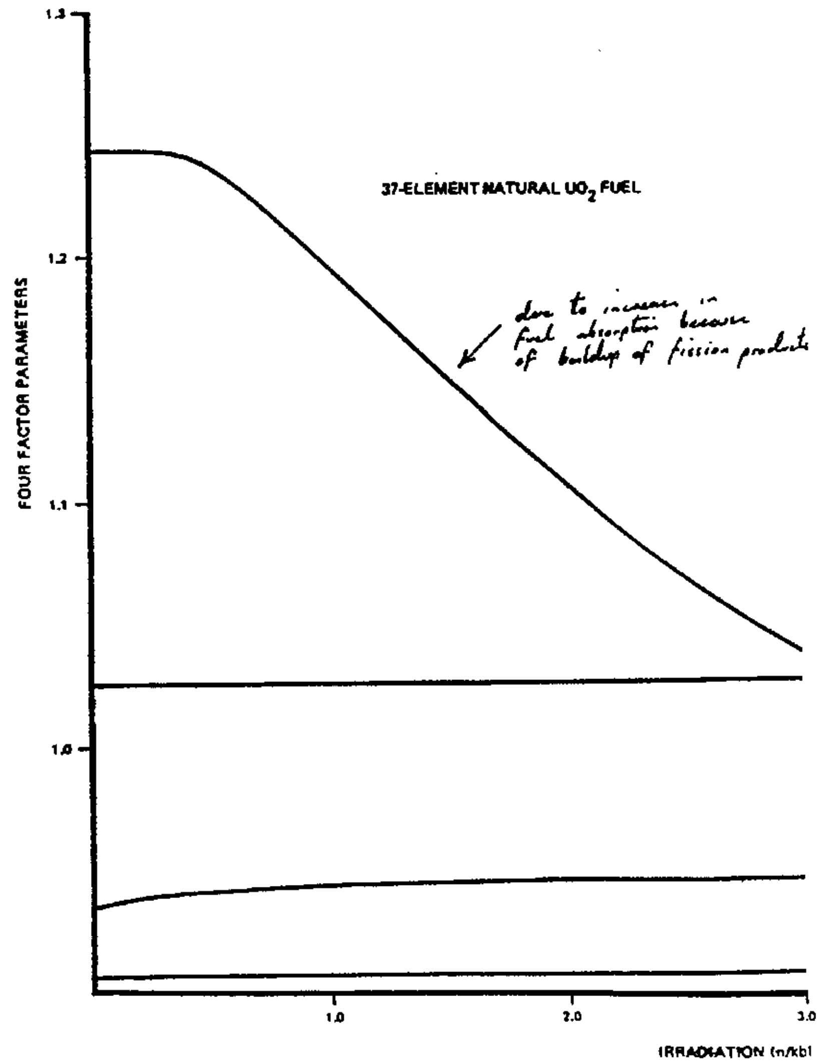
η = thermal reproduction factor (number of fast neutrons produced per thermal absorption in fuel)

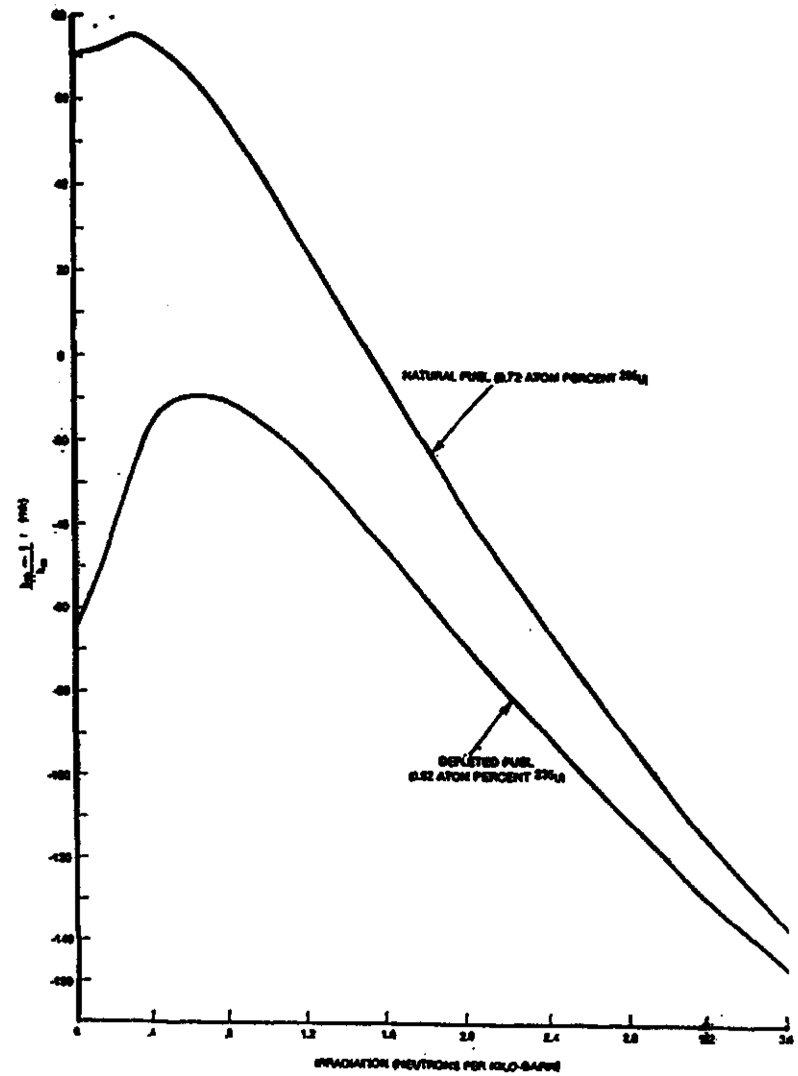
$k_{eff} = k_\infty P_f P_t$

P_f = fast non-leakage probability

P_t = thermal non-leakage probability


FUEL COMPONENT
NON-FUEL COMPONENTS
OUTSIDE REACTOR
FAST EFFECTS IN FUEL
FAST LEAKAGE
RESONANCE CAPTURE IN FUEL
THERMAL FISSION IN FUEL
LEAKAGE BETWEEN RESONANCE AND THERMAL ENERGIES
THERMAL ABSORPTION IN STRUCTURAL MATERIALS, COOLANT AND MODERATOR
1 NEUTRON


37-ELEMENT NATURAL UO_2 FUEL
due to increase in fuel absorption because of buildup of fission products
FOUR FACTOR PARAMETERS
1.3
1.2
1.1
1.0
1.0
2.0
3.0
IRRADIATION (n/kb)


NATURAL FUEL (0.72 ATOM PERCENT 235U)
DEPLETED FUEL (0.52 ATOM PERCENT 235U)
IRRADIATION (NEUTRONS PER KILO-BARN)

PPV Continued...

From the four factors, the 2-group cell cross-sections are computed.

This is done first at 0 irradiation (fresh fuel). The code then advances the irradiation value by a defined increment, solves the burnup equations to calculate the new isotopic concentrations, and then repeats the cell calculation.

The end result is a fuel table - table of cross-sections versus irradiation (for a given set of POWDERPUFS-V inputs).

Properties of any given bundle to which this input set applies are then obtained by interpolating in the fuel tables at the (known) bundle irradiation.

Powderpufs-V (Continued)

Powderpufs-V requires a set of 90 input values. This is the "R000" array.

The inputs can be grouped into a number of categories:

- Geometric specification of lattice cell
- Materials specification
- Atomic purities and isotopic compositions
- Physical properties such as densities and temperatures
- Saturating-fission-product control
- Initial guesses
- Run-control data
- Selection of major calculation options

TABLE 3.1
ITEMS IN POWDERPUFS-V INPUT

ITEM	DESCRIPTION
1	Wescott spectral parameter r
2	Fuel neutron temperature
3	Moderator density
4	Moderator temperature
5	Coolant density
6	Fuel density
7	Fuel temperature
8	Annuli neutron temperature
9	Moderator neutron temperature
10	Sheath absorption factor
11	Rubberband perimeter
12	Total fuel perimeter
13	Coolant thickness
14	Number of annuli
15	Moderator purity
16	Sheath material code
17	Void volume
18	Fuel volume
19	Sheath volume
20	Coolant volume in homogenized zone
21	Radius of homogenized zone
22	Outside radius of first annulus
23	Outside radius of second annulus
24	Outside radius of third annulus
25	Outside radius of fourth annulus
26	Outside radius of fifth annulus
27	Coolant temperature
28	Total coolant volume
29	Flux ratio
30	Lattice pitch

TABLE 3.1 (CONTINUED)
ITEMS IN POWDERPUFS-V INPUT

ITEM	DESCRIPTION
31	Coolant material code
32	Material code of first annulus
33	Material code of second annulus
34	Material code of third annulus
35	Material code of fourth annulus
36	Material code of fifth annulus
37	Initial flux estimate
38	U238 resonance capture fraction
39	Fast neutron yield cross section
40	Fast neutron non-escape probability
41	Fuel material code
42	Fuel heat rating
43	Power-to-coolant fraction
44	Initial exposure for a perturbed run
45	Neutron temperature convergence criterion
46	Bundle length
47	Pu-240 self shielding factor
48	Not used
49	Moderator poison concentration
50	Nuclei per mass of fuel
51	Exposure increment
52	D_2O coolant purity
53	DEBMS convergence criterion
54	Westcott spectral parameter convergence criterion
55	Maximum exposure
56	Lattice arrangement indicator
57	Geometrical buckling
58	Xenon macroscopic absorption cross section
59	Pu-240 convergence criterion
60	$\hat{\phi} / \hat{\phi}_{max}$

TABLE 3.1 (CONTINUED)
ITEMS IN POWDERPUFS-V INPUT

ITEM	DESCRIPTION
61	Initial Th-232 concentration
62	Initial U-233 concentration
63	Initial U-234 concentration
64	Initial U-235 concentration
65	Initial U-236 concentration
66	Initial U-238 concentration
67	Initial Pu-239 concentration
68	Initial Pu-241 concentration
69	Initial Pu-241 concentration
70	Initial Pu-242 concentration
71	Isotopic density indicator
72	Number of rods in fuel bundle
73	Perturbation control
74	Not used
75	Not used
76	Not used
77	Not used
78	Thermal Pu-239 production control
79	Saturating-fission-product control
80	Printout control
81	Radial buckling of central region
82	EXTERMINATOR calculation control
83	PERIGEE calculation control
84	Burnup control
85	T_{nf} and r calculation control
86	Extrapolated length of reactor
87	Core radius
88	Reactor radius
89	Radial form factor
90	Total fission power