united nations
educational, scientific
and cultural
organization

international atomic
energy agency

the
abdus salam
international centre for theoretical physics

ICTP 40th Anniversary

SMR.1555 - 1

Workshop on
Nuclear Reaction Data and Nuclear Reactors:
Physics, Design and Safety

16 February - 12 March 2004

Introduction to WIMS

Les HUTTON
SERCO Assurance
Winfrith Technology Centre
Dorchester
Dorset
DT2 8UX
U.K.

serco

Serco Assurance

An Introduction to WIMSD

J L Hutton

1 March 2004

Aim of Course

- Train new users to set up WIMS input files for standard situations
- Gain familiarity with the architecture of the code and to run calculations
- Give an understanding of the basic physics methods and approximations
- Obtain user feedback on WIMS
- Hands on course
  - workshop on each part of the calculation

WORKSHOPS

- Gain familiarity with architecture of the code
- Set up input for standard situations
- Run calculations
- Illustrate major features of the code

Les Hutton

- 35 years experience in Reactor Physics
- Long involvement with the development of WIMS
- Worked on most reactor types
- Developed CACTUS, PRIZE and HEAD
- Developed Monte Carlo Methods
  - MAX
  - MONK8
- Currently working on 3D CACTUS and Perturbation methods in Monte Carlo

David Powney

- 15 Years in the WIMS development and applications area
- Transport methods especially characteristics
- PWR and VVER lattice physics
- PWR and VVER core analysis
- AGR design route
- Currently working on 3D CACTUS, RBMK core analysis and modelling vacant channels in Magnox.

INTRODUCTION TO WIMS

- QUESTIONS
- (1) What is WIMS?
- (2) Why use it?
- (3) Why were there so many versions?
- (4) Which version should I use?
- (5) What does the input look like?
- (6) What does the output mean?

INTRODUCTION TO WIMS

(1) What is WIMS?

Winfrith Improved Multigroup Scheme

Deterministic Methods:

- discrete energy groups
- discrete spatial meshes
- simplified geometry
- calculates fluxes, k, reaction rates, etc.

Monte Carlo Methods:

- complex geometry
- benchmarking

INTRODUCTION TO WIMS

(2) Why use WIMS?

Analysis of experiments:	flux, buckling, reaction rates, integral data checking
Power reactor studies:	design, assessment, operation, generation of parameters or feedbacks including burnup, temperatures etc.
Criticality studies:	excellent survey tool, in support of Monte Carlo

INTRODUCTION TO WIMS

(3) Why all the versions?

HISTORY:

WIMSD	1963 - 1965	Integration of new and old methods for pin cells and clusters.
	1965 - 1980	Various ‘minor’ additions
WIMSE	1968 -	Modularity; Flexibility; Generality
LWRWIMS	1970 -	Development of special methods for LWRs
WIMS7	1995	Combined features of WIMSD, LWRWIMS and WIMSE for workstation environment

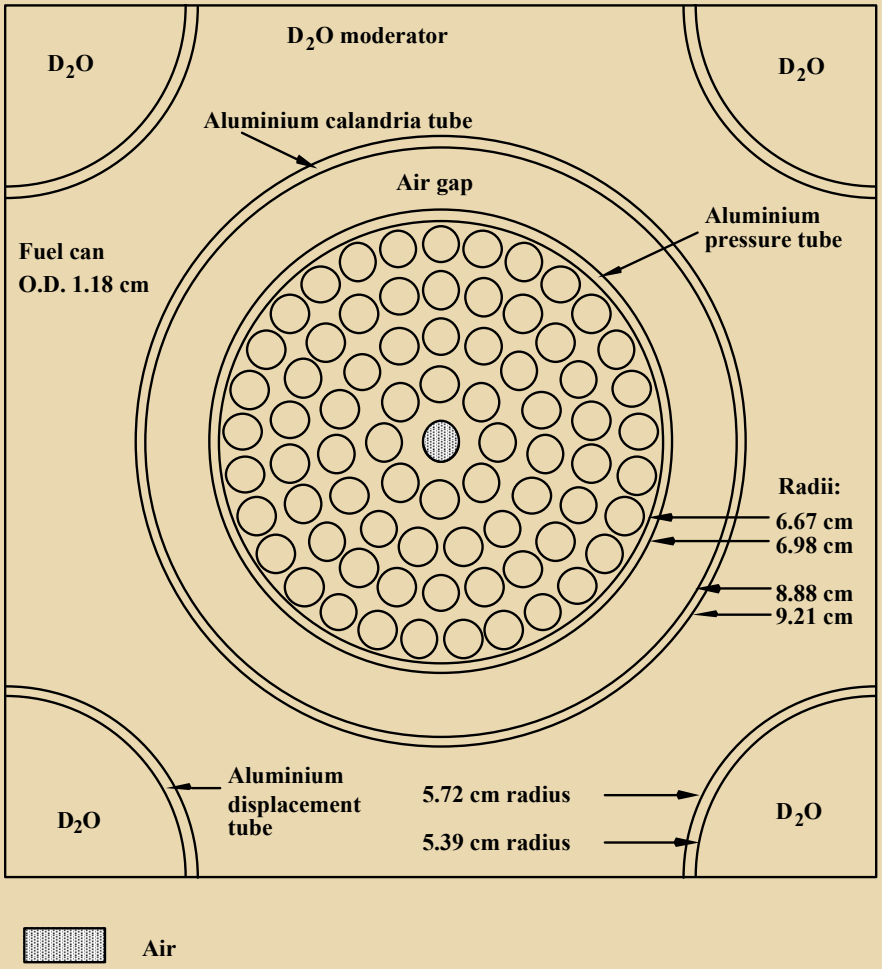
INTRODUCTION TO WIMS

(4) Which version of WIMS?
USE:

WIMSD	for homogeneous, slab, pincell or cylindrical cluster geometries.
LWRWIMS	for PWR or BWR assembly geometries (including regular pin arrays, e.g. small experimental cores, transport flasks etc.).
WIMS	for all types of problem

(See Beginner's Guide (AEEW-R 2211) in WIMS ANSWERS Documentation.)

LATTICE CELL FOR SGHWR



HISTORICAL DEVELOPMENT OF WIMS

Early 1960s

Available codes:

METHUSELAH (PATRIARCH SCHEME).

DSN	(multi-group transport solution in 1D cylindrical or slab geometry).
MOCUP	(Monte Carlo calculation of resonance events).

Led to development of THULE.

DEVELOPMENT OF WIMSD

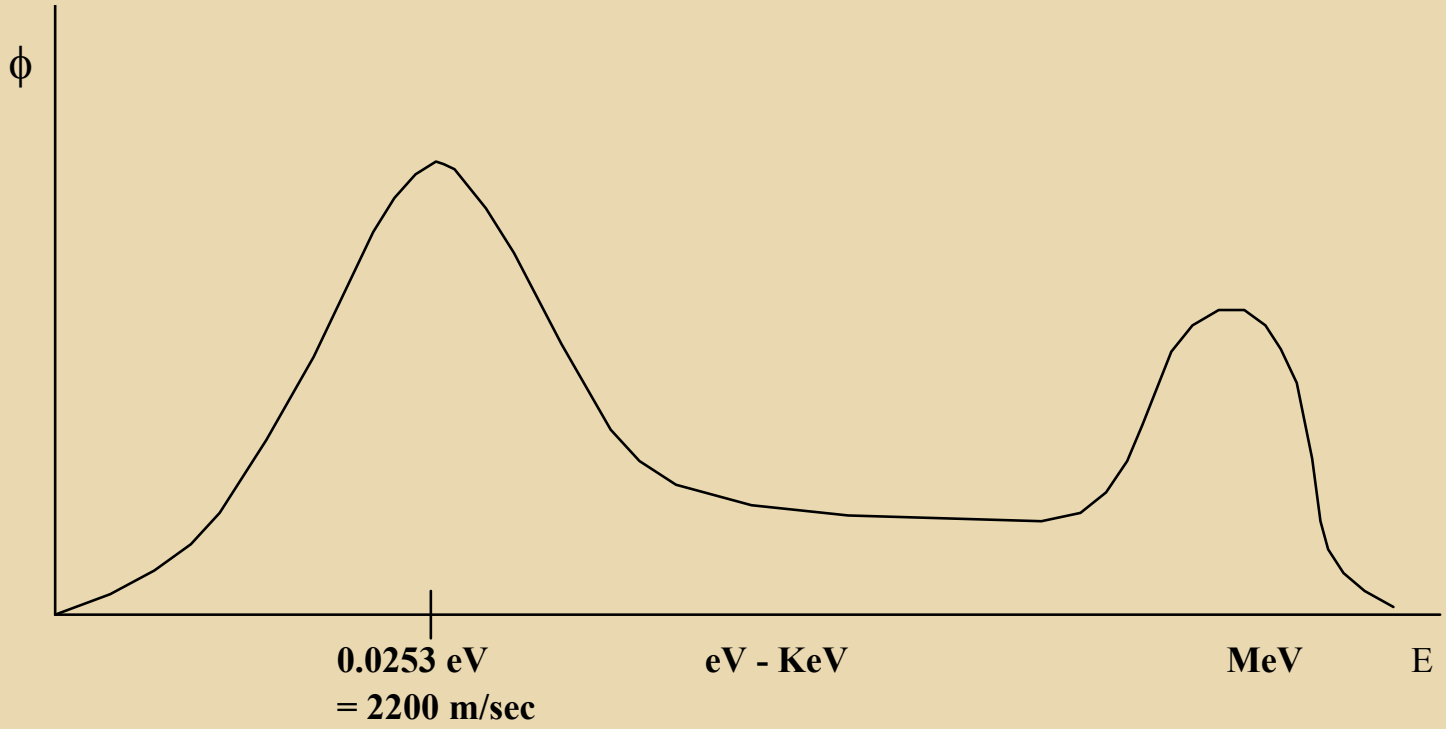
Requirement for automated self-consistent treatment of graphite and water (H2O and D2O) moderator systems led to WIMS (versions A, B, C, D).

1965	First use for experimental assemblies - 20m/case: (regular clusters and pins).
1966	Plate geometry and burnup added.
1968	Version D.
1980	Version D4 major development ceased.
1996	WIMSD5 - ‘NEA’ version with foreign developments incorporated

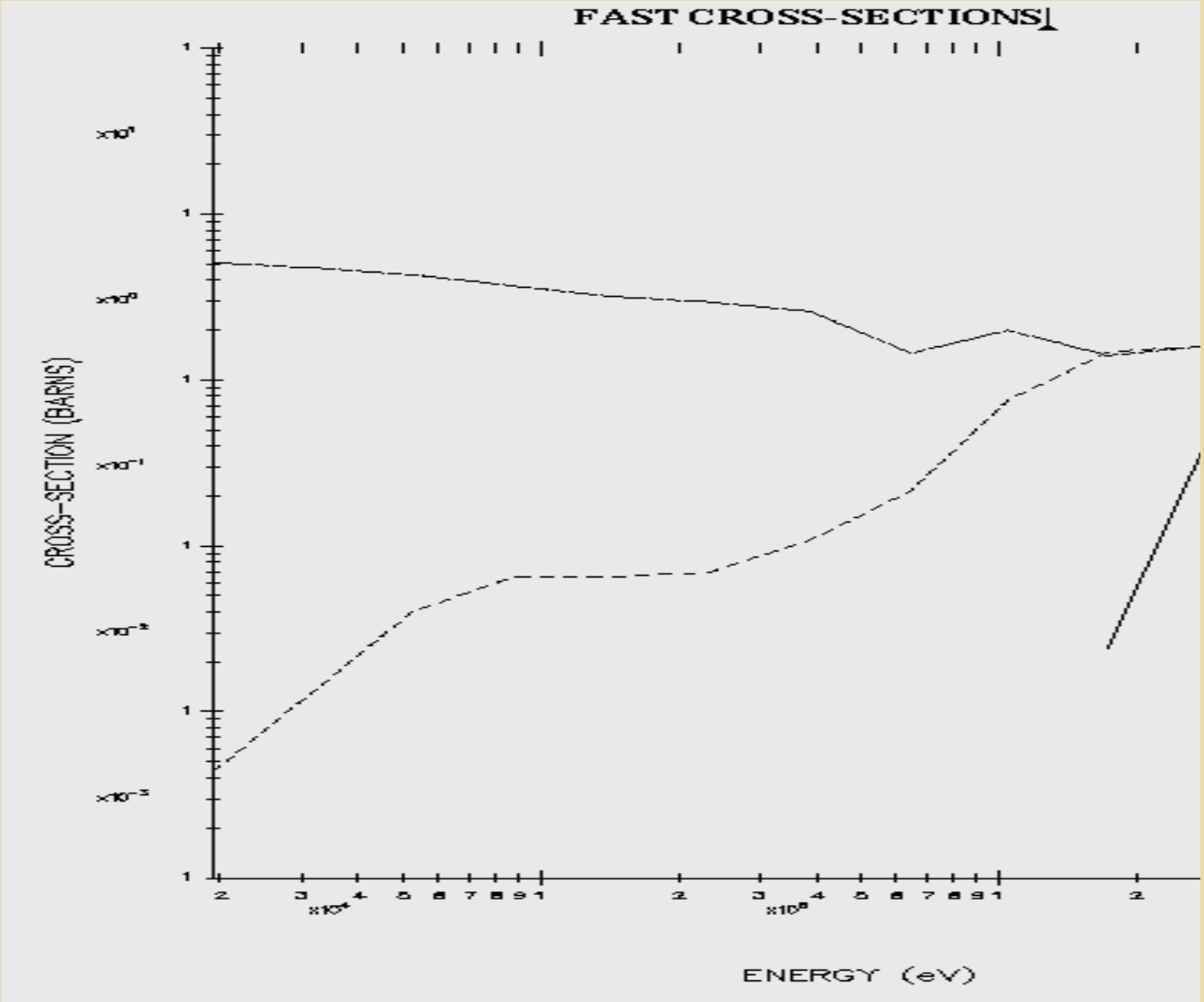
NUCLEAR DATA

- Variation of cross sections with energy
- Spectral averaging
- Group representation
- WIMS library
- Resonance treatment
- Few-group condensation

REACTOR NEUTRON SPECTRUM



THRESHOLD REACTIONS IN FAST REGION

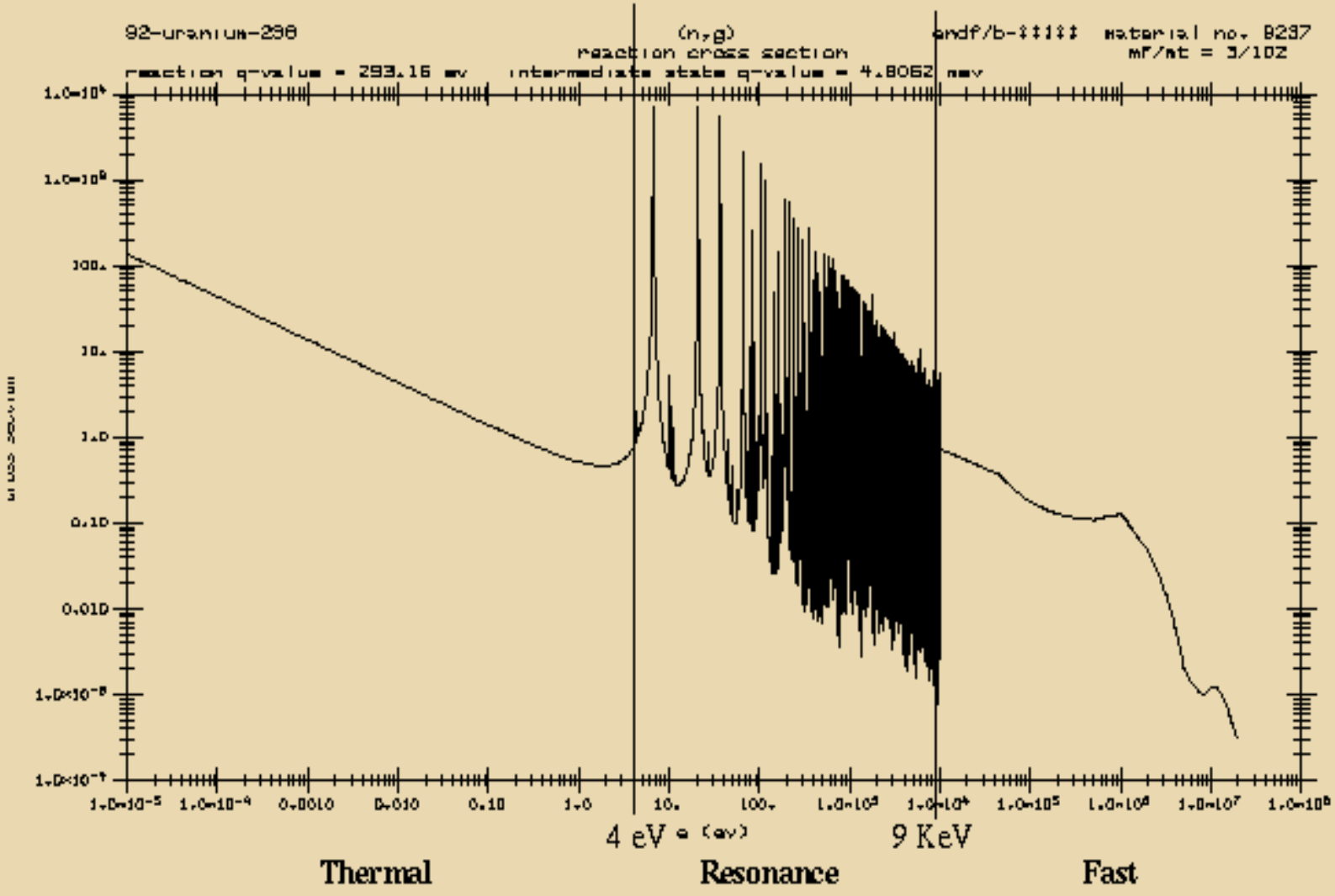


WIMS DATA LIBRARY

- FAST REGION:
- 10MeV - 9.118 KeV
- 14 Groups, 1/2 Lethargy Intervals

- Fission neutrons born
- Threshold fission in U238, Pu240
- Low cross section, hence long neutron paths
- Diverse reactions: inelastic scatter, (n,2n)
- Anisotropic scatter
- Temperature independent

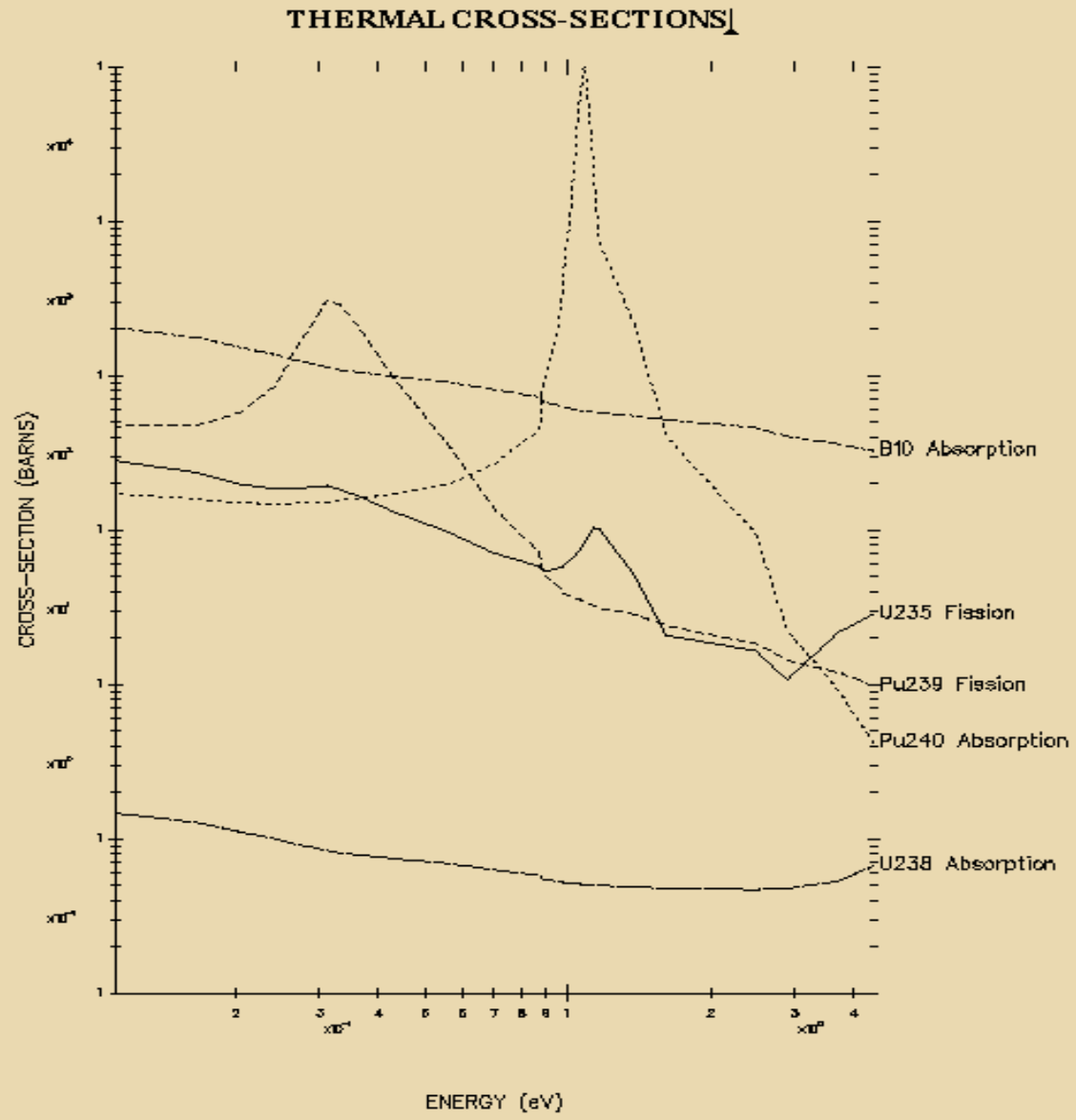
WIMS ENERGY REGIONS



WIMS DATA LIBRARY

- RESONANCE REGION:
- 9.118 KeV to 4eV;
- 13 Groups, ~1/2 lethargy intervals.
- Constant moderator cross sections; ~ isotropic (C of M).
- Resonances in intermediate and heavy nuclei; temperature dependent.
- Short range effects due to very high cross sections, hence difficult modelling problems.

ABSORPTION CAPTURE AND FISSION CROSS-SECTIONS

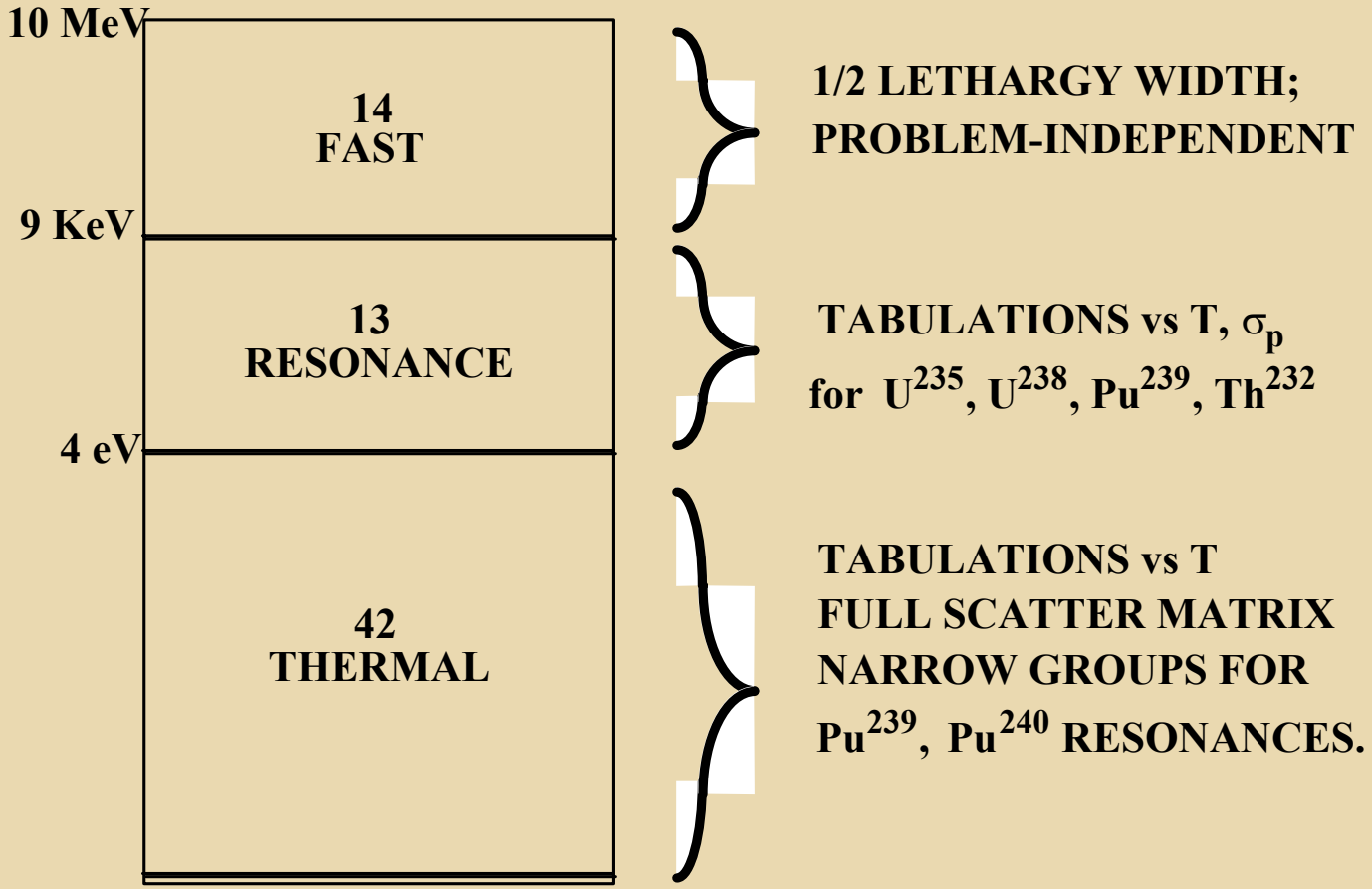


WIMS DATA LIBRARY

- THERMAL REGION:
- 4.0 eV to 0 eV
- 42 groups, various intervals

- Thermal motion of light nuclides becomes significant - scattering law
- Resonances broader relative to ΔE in collision, hence 'slowly' varying cross sections
- Large cross sections of 1/V nuclides

WIMSD LIBRARY 69 GROUPS



For each nuclide: σ_a σ_{tr} σ_s σ_f $\sigma\sigma_p$ $\sigma\sigma_s$ $\sigma_{n,2n}$

TRANSPORT CORRECTION

In multigroup form $\Sigma_{tr} = \Sigma - \bar{\mu}\Sigma_S$

$$\Sigma_{tr,g} = \Sigma_g - \bar{\mu}\Sigma_{s,g}$$

$$\Sigma'_{s,g' \to g} = \Sigma_{s,g' \to g} - \delta_{gg'}\bar{\mu}_g\Sigma_{s,g}$$

to preserve the energy transfer properties.

Note that, especially for narrow groups, this can lead to negative values of

$$\Sigma'_{s,g \to g}$$

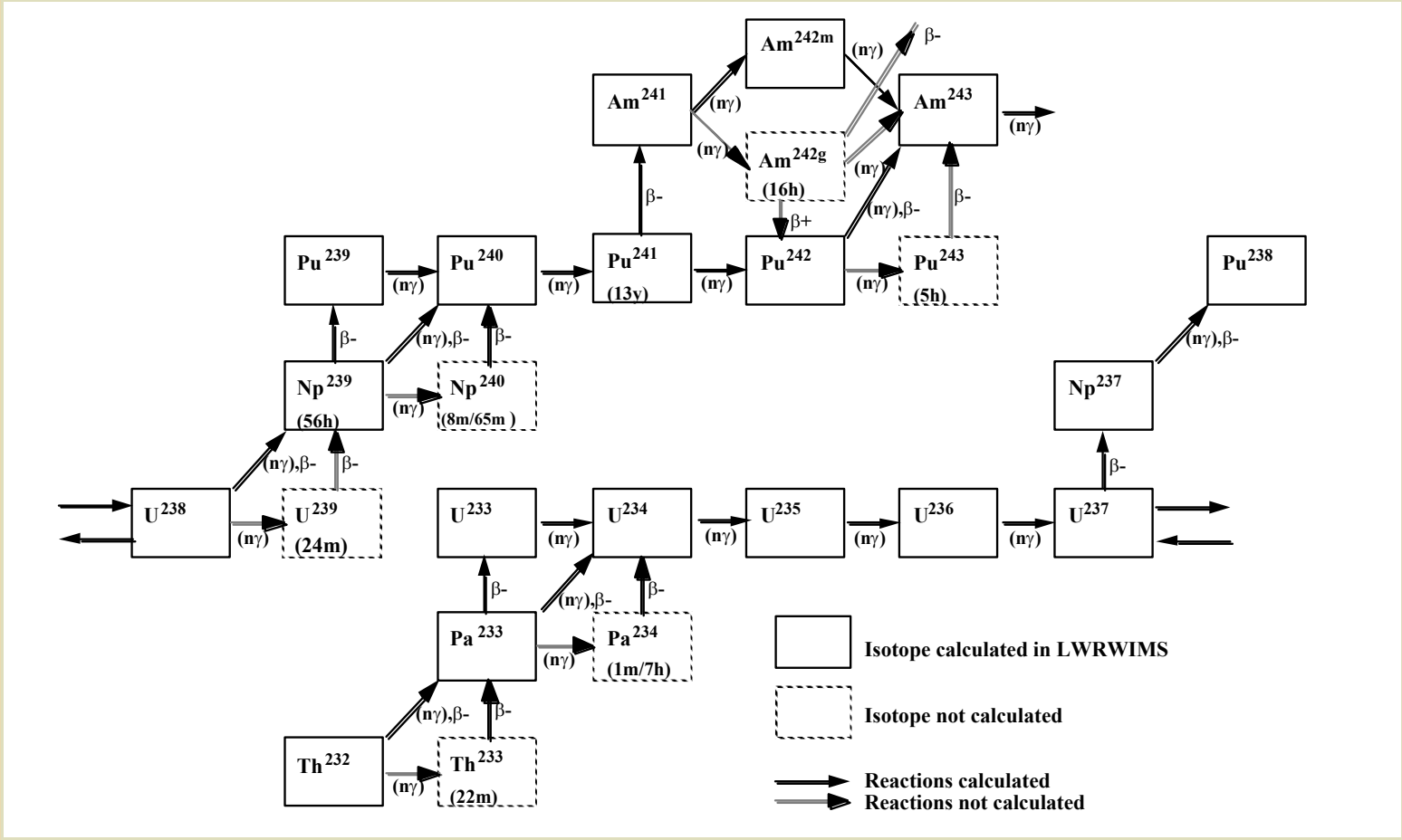
$$\left[\bar{\mu} \sim \frac{2}{3A}, \text{ for elastic scattering} \right]$$

e.g. for hydrogen $\sigma_s \sim 20\,b$

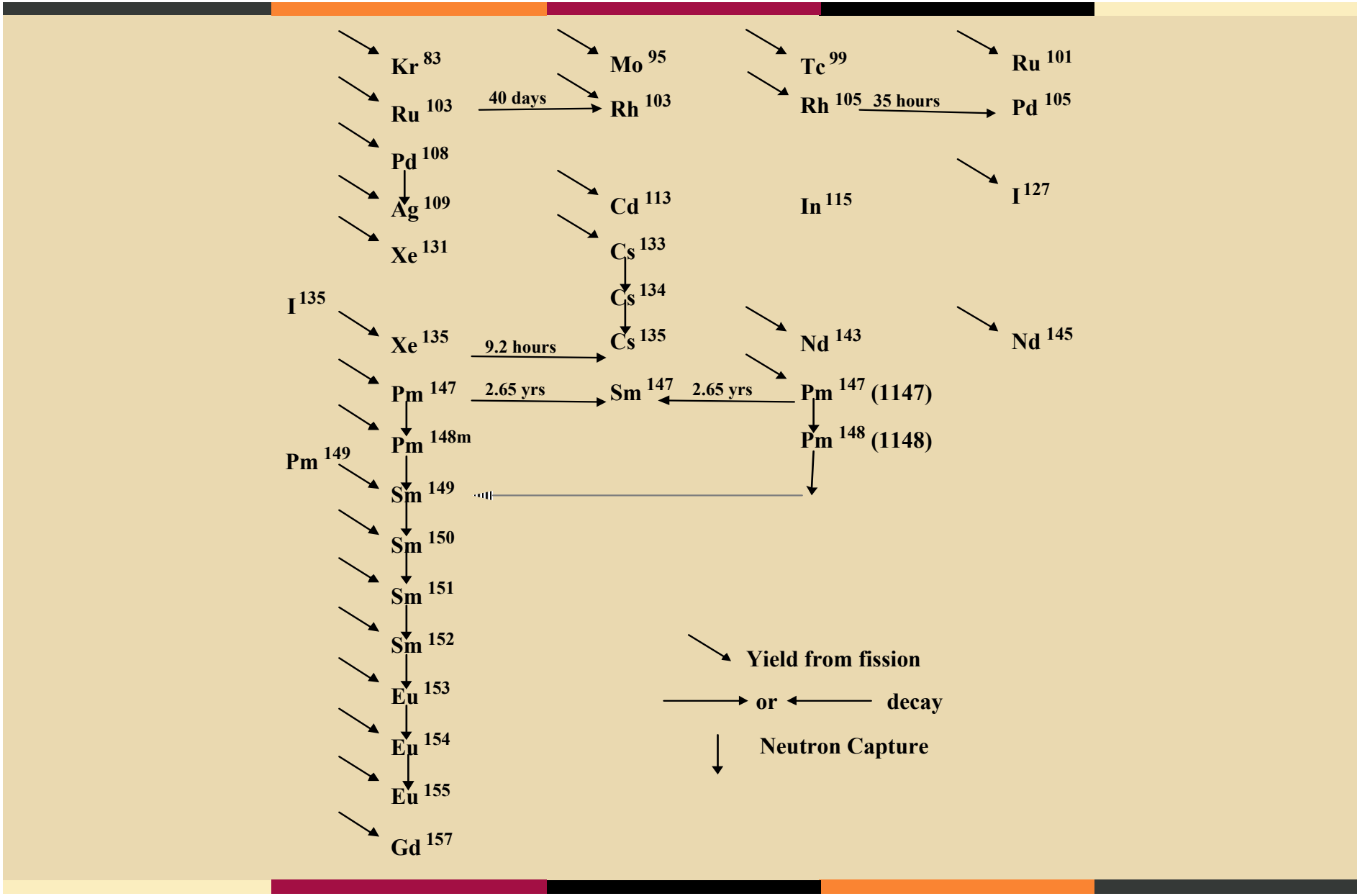
$\sigma_{tr} \sim 7\,b$

if outscatter > 7b then self scatter is negative

PRINCIPAL LINKS IN THE HEAVY ATOM BURNUP CHAINS



FISSION PRODUCT CHAINS IN WIMS LIBRARY



WIMS LIBRARY GROUP STRUCTURES

69 Group Library	28 Group Library	Energy (eV)
1	1	10-6.0655x10 6
2		6.0655-3.679x10 6
3		3.679-2.231x10 6
4	2	2.231- 1.353x10 6
5		1.353-0.821x10 6
6	3	821,000-500,000
7		500,000-302,500
8		302,500-183,000
9		183,000-111,000
10	4	111,000-67,340
11		67,340-40,850
12		40,850-24,750
13		24,750-15,030
14		15,030- 9,118
15	5	9,118-5530.0
16		5530.0-3519.1
17		3519.1-2239.45
18		2239.45-1425.1
19		1425.1-906.898
20		906.898-367.262

69 Group Library	28 Group Library	Energy (eV)
21		367.262-148.728
22	**6**	148.728-75.5014
23		75.5014-48.052
24		48.052-27.700
25		27.700-15.968
26	**7**	15.968-9.877
27	**8**	9.877-4.00
28	**9**	4.00-3.30
29	**10**	3.30-2.60
30	**11**	2.60-2.10
31	**12**	2.10-1.50
32		1.50-1.30
33	**13**	1.30-1.15
34	**14**	1.15-1.123
35		1.123-1.097

WIMS LIBRARY GROUP STRUCTURES

69 Group Library	28 Group Library	Energy(eV)
36	15	1.097-1.071
37		1.071-1.045
38		1.045-1.020
39	16	1.020-0.996
40		0.996-0.972
41	17	0.972-0.950
42	18	0.950-0.910
43		0.910-0.850
44	19	0.850-0.780
45		0.780-0.625
46	20	0.625-0.500
47		0.500-0.400
48	21	0.400-0.350
49		0.350-0.320
50	22	0.320-0.300
51		0.300-0.280
52		0.280-0.250
53	23	0.250-0.220
54		0.220-0.180
55		0.180-0.140
56	**24**	0.140-0.100
57		0.100-0.080
58		0.080-0.067
59	**25**	0.067-0.058
60		0.058-0.050
61	**26**	0.050-0.042
62		0.042-0.035
63		0.035-0.030
64	**27**	0.030-0.025
65		0.025-0.020
66		0.020-0.015
67	**28**	0.015-0.010
68		0.010-0.005
69		0.005-0.000

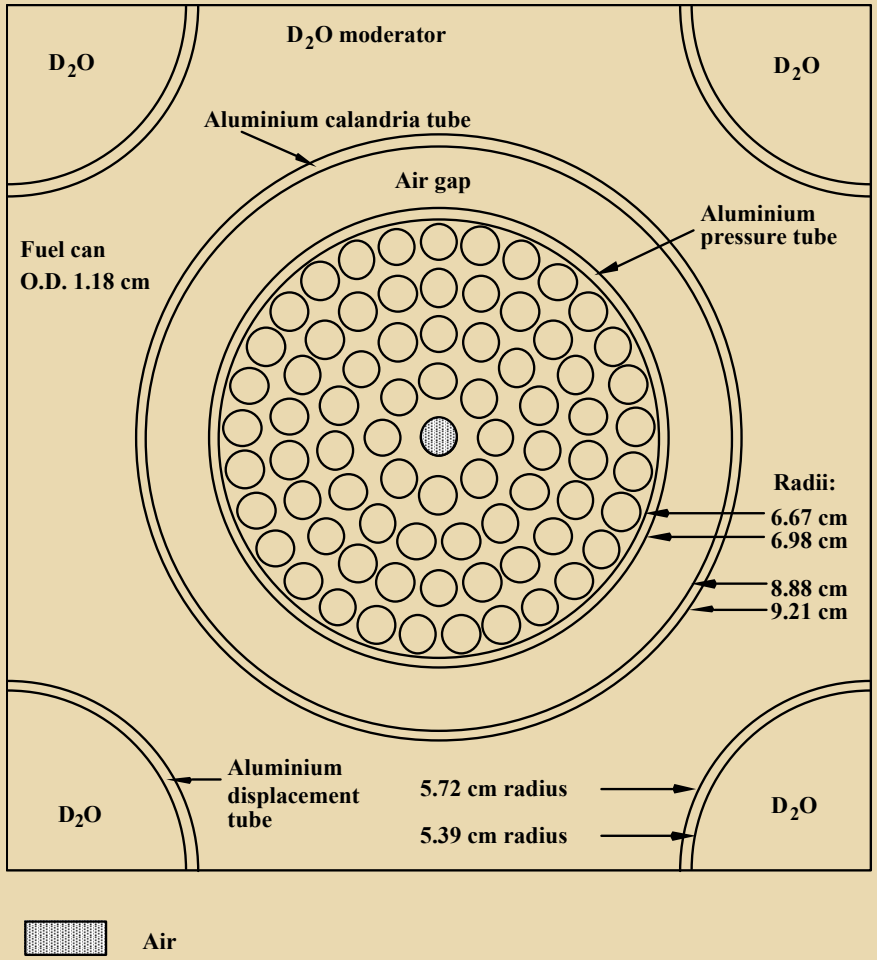
WIMS LIBRARY STRUCTURE

WIMSD	WIMSE & LWRWIMS	WIMS
Number of Nuclides, Groups	Number of Nuclides, Groups	Datagrams
List of Nuclides	List of Group Boundaries	
List of Group Boundaries	List of Nuclides	
Fission Spectrum	Cross-Sections for each Nuclide in General Format	
Burnup Data for each Nuclide		
Cross-Sections for each Nuclide		
Resonance Tabulations for each Group		
P1 Scattering for H, D, O, C		

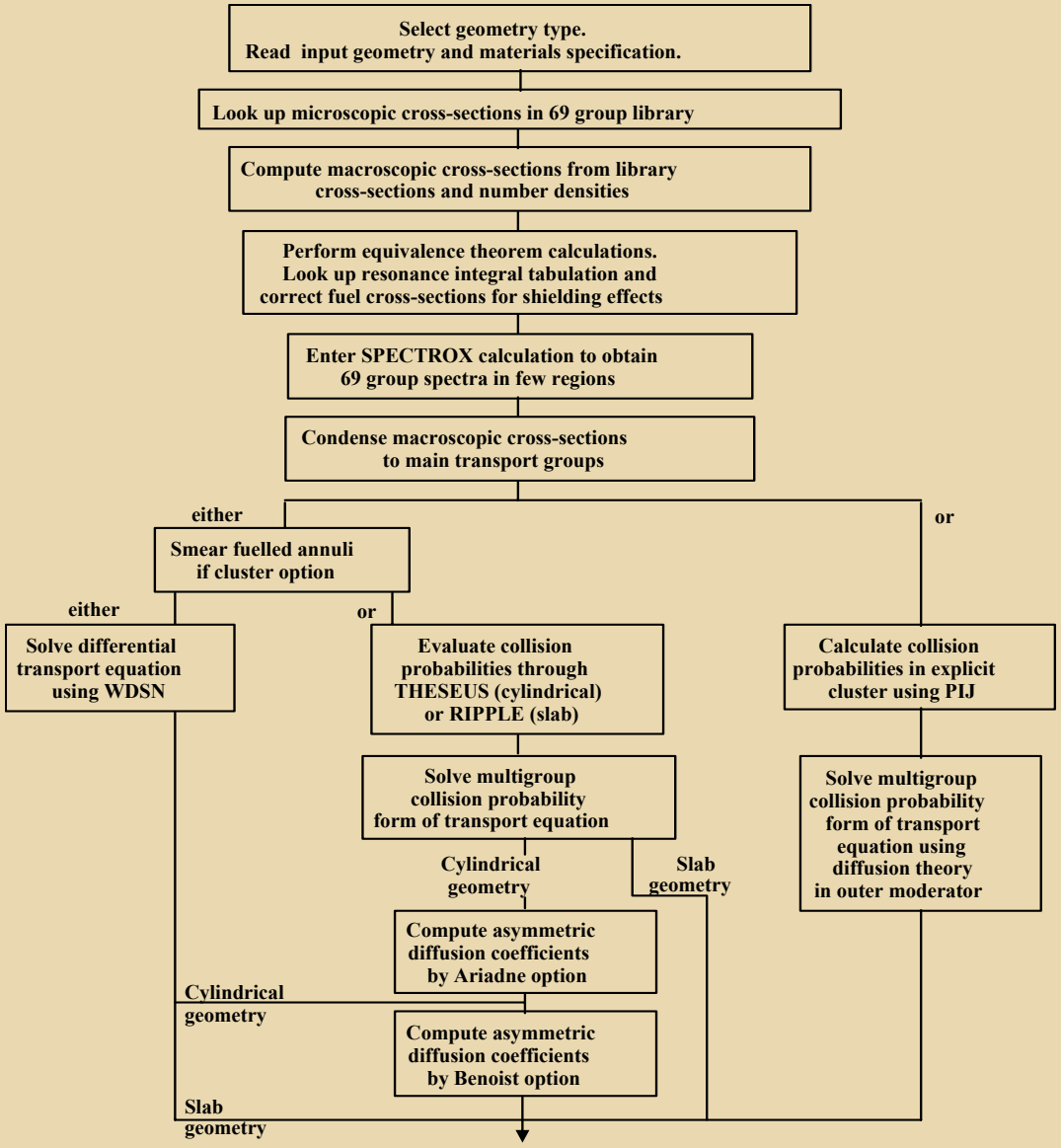
WIMSD Architecture

- Block Diagram
- Chains
- Readdata
- Geometry

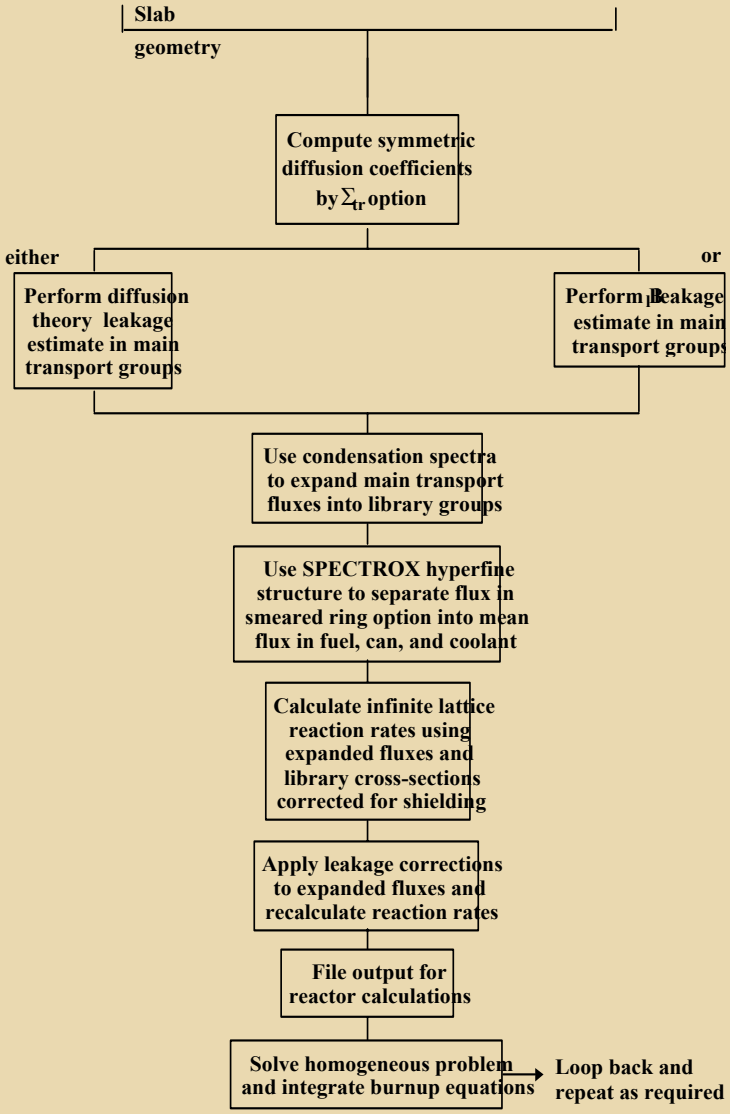
SGHWR LATTICE GEOMETRY



WIMSD BLOCK DIAGRAM



WIMSD BLOCK DIAGRAM



WIMSD ‘CHAINS’

Prelude	Prelude Input and Storage allocation
Chain 1	Input of MAIN DATA
Chain 2	Microscopic Cross Sections
Chain 3	Resonance Shielding
Chain 4	SPECTROX
Chain 5	Smearing and Condensation
Chain 6	DSN
Chain 8	PIJ
Chain 9	PRIZE
Chain 10	-
Chain 11	Unsmearing
Chain 12	Burnup

WIMSD ‘CHAINS’

Chain 13	K-infinity Edit
Chain 14	K-effective
Chain 15	Nuclide reaction edits
Chain 16	Link to WIMS - later versions

READDATA

Input is in the form of:
- CODEWORD (upper or lower case) followed by numerical data items.
Only the first 4 letters of a codeword are relevant.
Data items may be real or integer or containing E for exponent, but must contain no blanks(eg. 1.0e-2).

Data items for one codeword may occupy several lines (without $ signs) but must not extend beyond column 72.

Repeated items may be input as:
13@1 0 1 * (instead of 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1)
3 (1 2 3) * (instead of 1 2 3 1 2 3 1 2 3)

An asterisk(*) indicates that all the following information on the current line is a comment

DISCRETISATION OF GEOMETRY

Infinite Homogeneous Problem

- No geometry subdivision required.

Heterogeneous Problem

- Minimum subdivision: one calculation "mesh" per material region

- In practice, material regions are normally subdivided into several meshes of about one transport mean free path in size (~ 1 cm in H_2O)

GEOMETRY OPTIONS

HOMOGENEOUS

SLAB

REGULAR PINCELL ARRAY

CLUSTER (PRESSURE TUBE)

MULTICELL

+ choice of boundary conditions

Typical cluster - subdivision into ~ 30 meshes

Computing time and storage vary as :

Number of groups x Number of meshes

Resonance Treatment

- Treated in next lecture
- WIMS uses Equivalence method
- Tabulates Resonance Integrals for HOMOGENEOUS systems on WIMS library
- Uses EQUIVALENCE to equate heterogeneous system to correct homogeneous resonance Integral
- Hence shielding for resonance nuclides

NEUTRON TRANSPORT THEORY

METHODS:

Differential Transport - DSN

Integral Transport - PERSEUS, PIJ, PRIZE.
(Collision Probabilities)

MAIN TRANSPORT CALCULATIONS

Sn Method	DSN	1D
Collision Probabilities	PERSEUS	Annular and Slabs
	PRIZE	r-z
	PIJ	r-θ(plus Square Boundary)
	SPECTROX	Pin in a Cluster

WIMS BASIC STRATEGY

1 SIMPLE GEOMETRY IN

69 groups x 3 meshes LIBRARY

GROUPS

SPECTROX & CONDENSE

2 COMPLEX GEOMETRY IN

6 groups x 30 meshes

FEW GROUPS

(69 x 3) + (6 x 30) < (69 x 30)

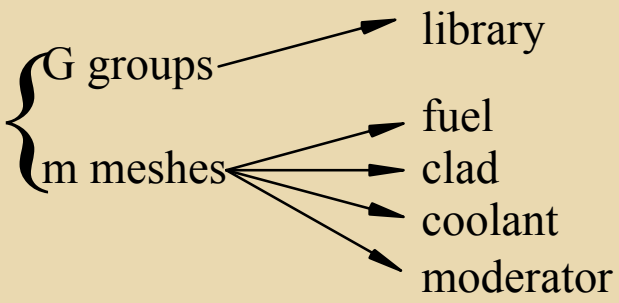
CLUSTER LATTICE CALCULATION

GEOMETRY

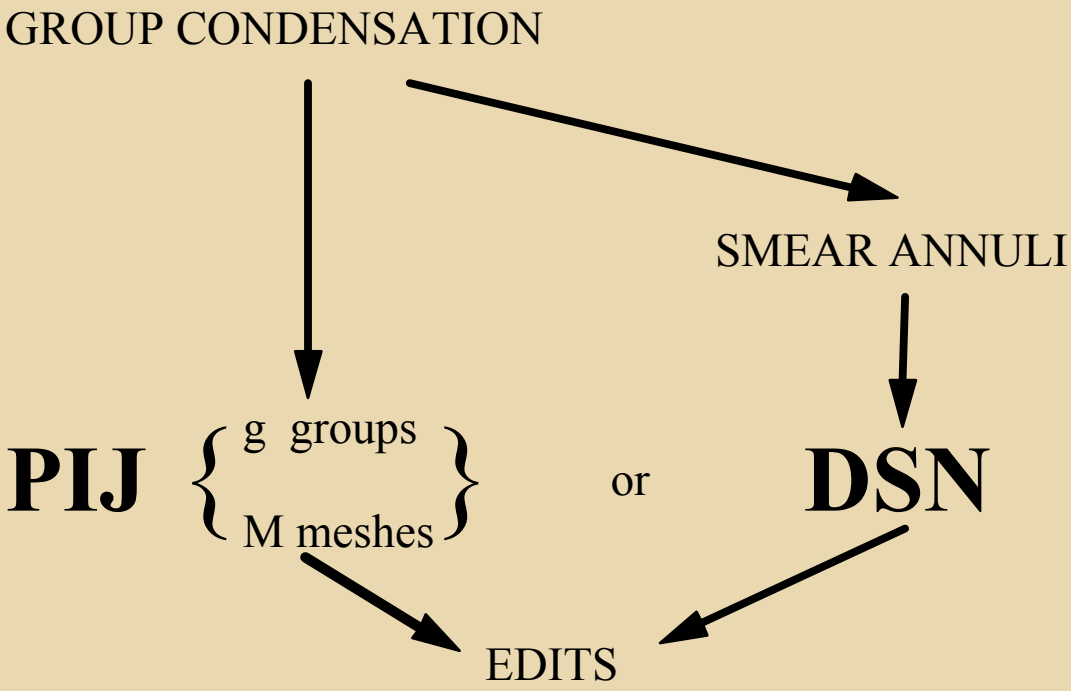
CROSS SECTIONS

RESONANCE SHIELDING

SPECTROX



CLUSTER LATTICE CALCULATION



FEW - GROUP CONDENSATION

Library Condensation: e.g. 69 to 28 Groups
or 172 to 69 Groups

WIMS Calculation: $Gm + gM < GM$

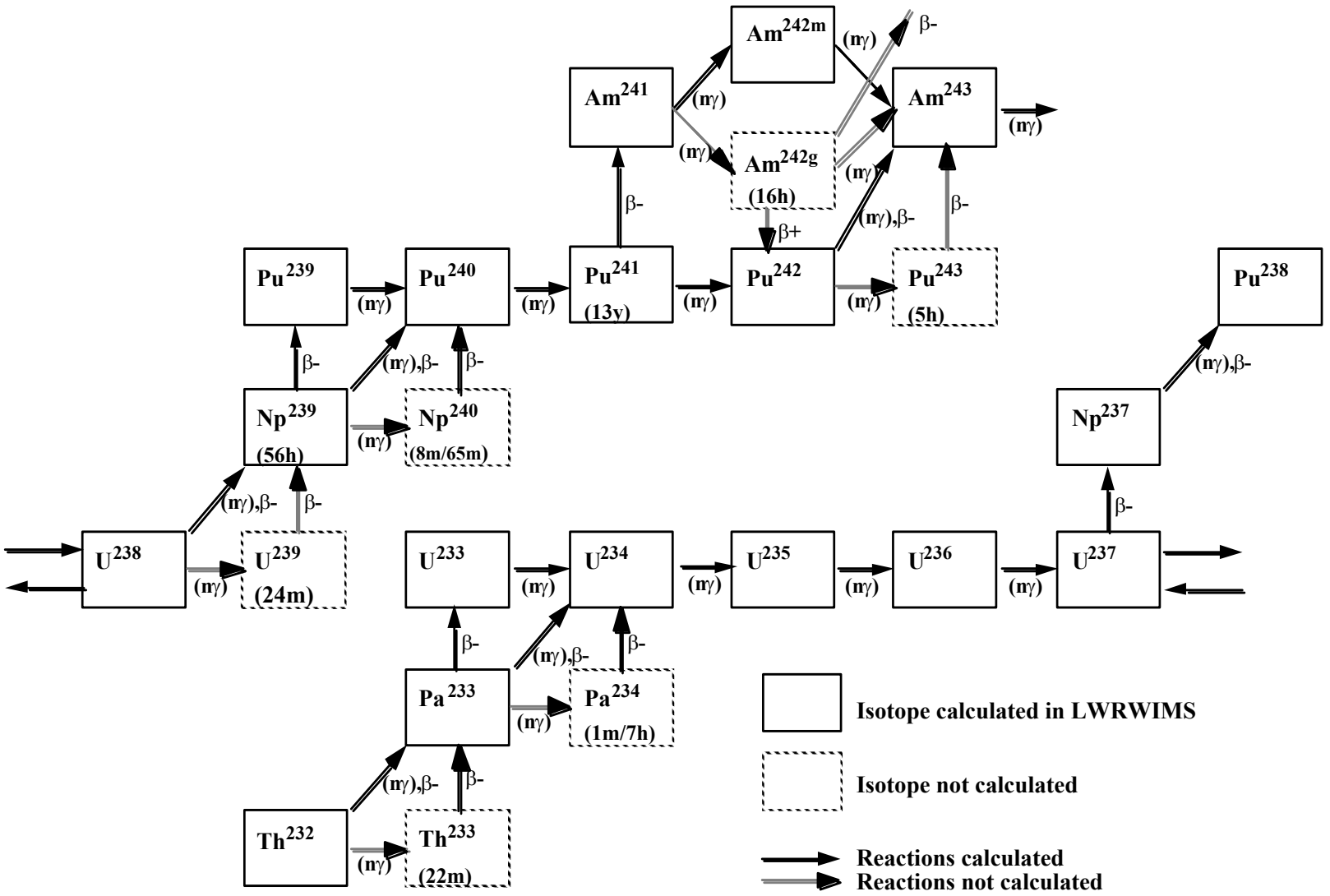
Factors In Choice Of Groups:

- Required accuracy
- Representation of leakage
- Plutonium
- Resonance treatment
- Constraints on edit group boundaries

DEPLETION

- Standard Options
- Optional Extras

PRINCIPAL LINKS IN THE HEAVY ATOM BURNUP CHAINS



DEPLETION EQUATIONS

DECAY AND ABSORPTION

$$\frac{dN_i}{dt} = -(\lambda_i + A_i) N_i$$

FISSION PRODUCT YIELD

$$+ \sum_j Y_{ji} F_j N_j$$

BRANCHING CAPTURE

$$+ \sum_j B_{ji} C_j N_j$$

DECAY

$$+ \lambda_k N_k$$

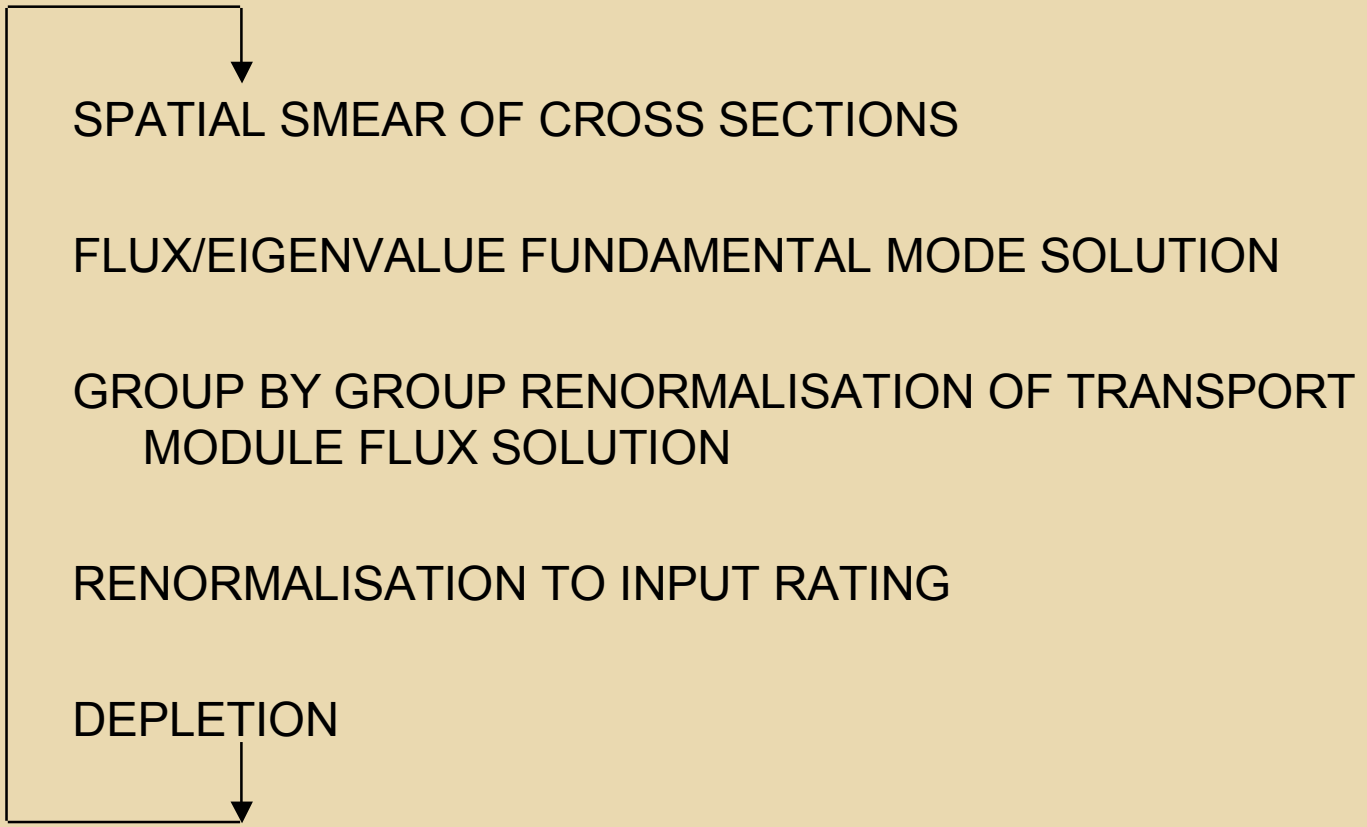
DEPLETION SOLUTION

$$\frac{d\mathbb{N}}{d\mathrm{t}} = \mathbb{A} \cdot \mathbb{N}$$

EULER METHOD
(First Order Taylor Expansion)

Automatic time step selection
Unstable for Xe transients

DEPLETION FLUX



OPTIONAL EXTRAS

- (a) ‘ALPHA’ VALUES
- (b) ‘FINE’ OPTIONS

ALPHA OPTION

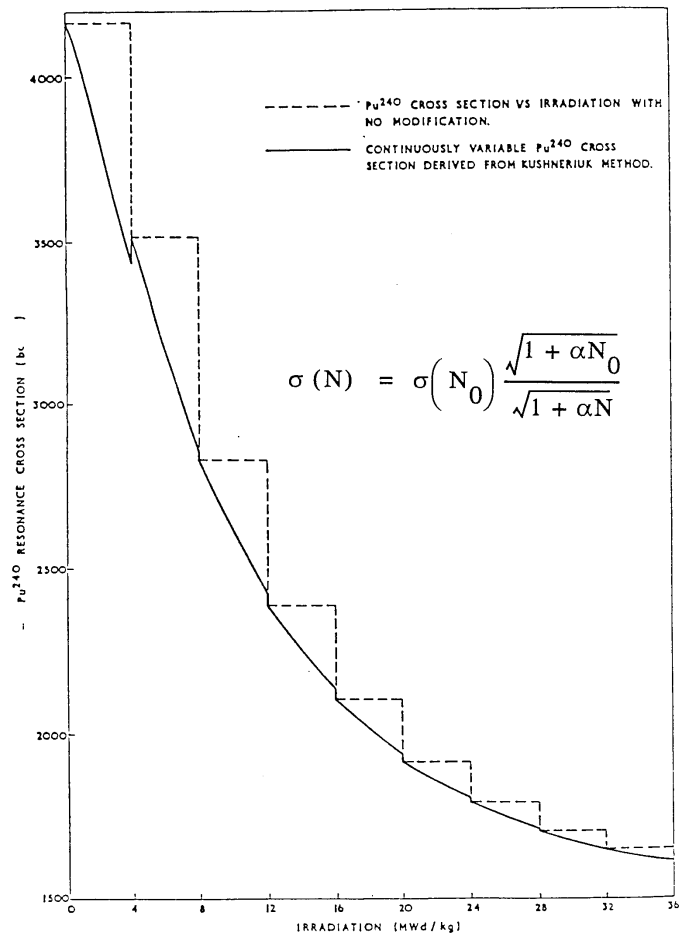
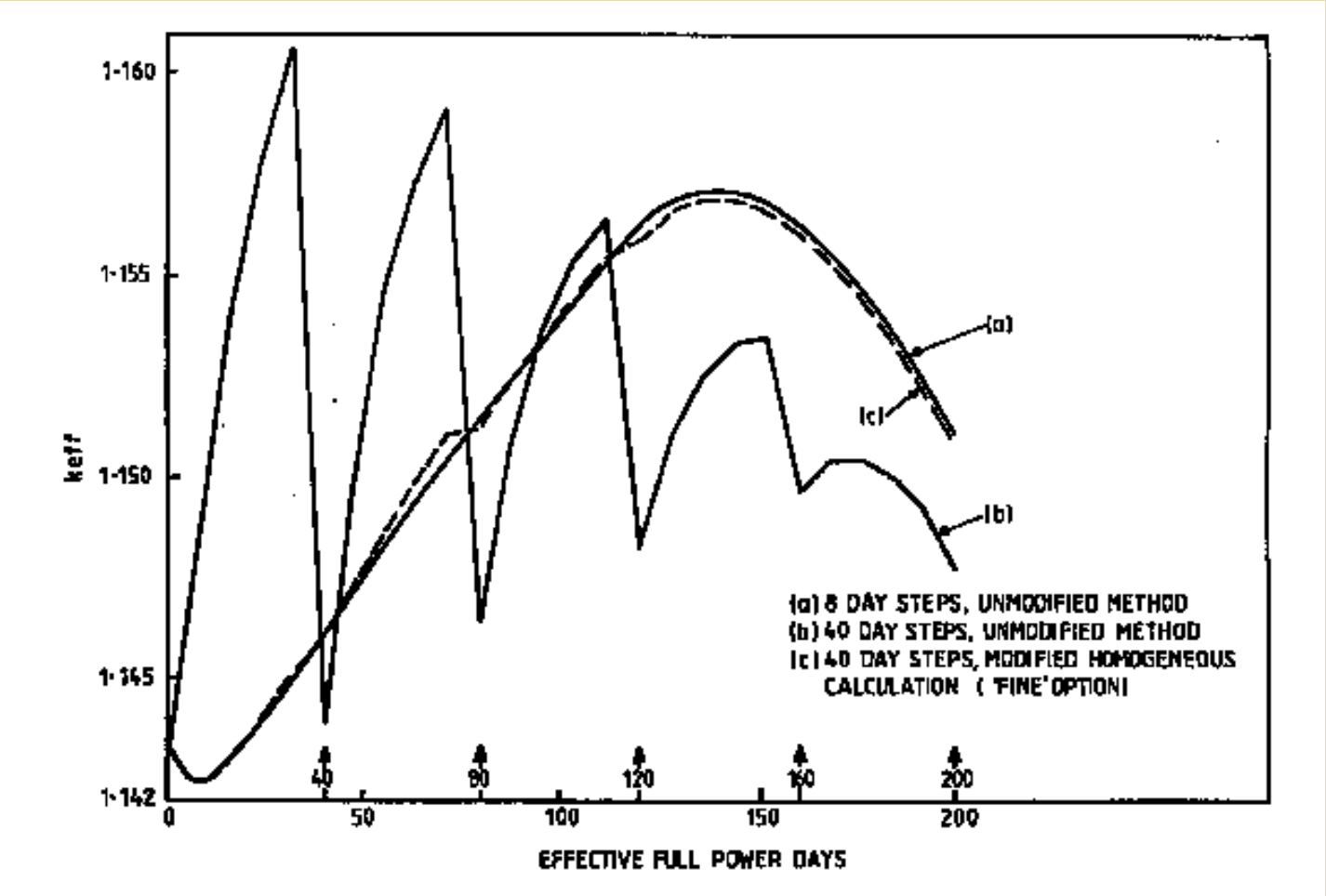
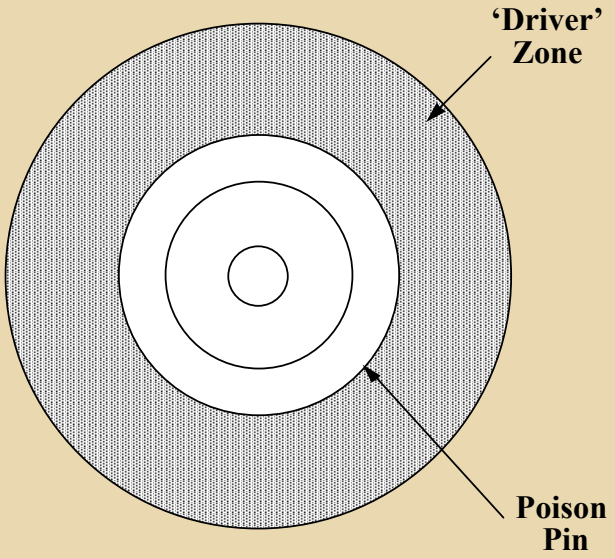


FIG. 7. Pu^{240} RESONANCE CROSS SECTION VS IRRADIATION

REACTIVITY OF A FUEL BUNDLE WITH 1 POISON PIN



‘FINE’ OPTION



- USERS SPECIFIED DRIVER ZONE
- COLLISION PROBABILITY CALCULATIONS OF POISON PIN FLUXES
- RENORMALISATION OF TRANSPORT MODULE REACTION RATES
- METHOD ALLOWS ALL REACTIONS INCLUDING FISSION