



the  
**abdus salam**  
international centre for theoretical physics

SMR/1220-7

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

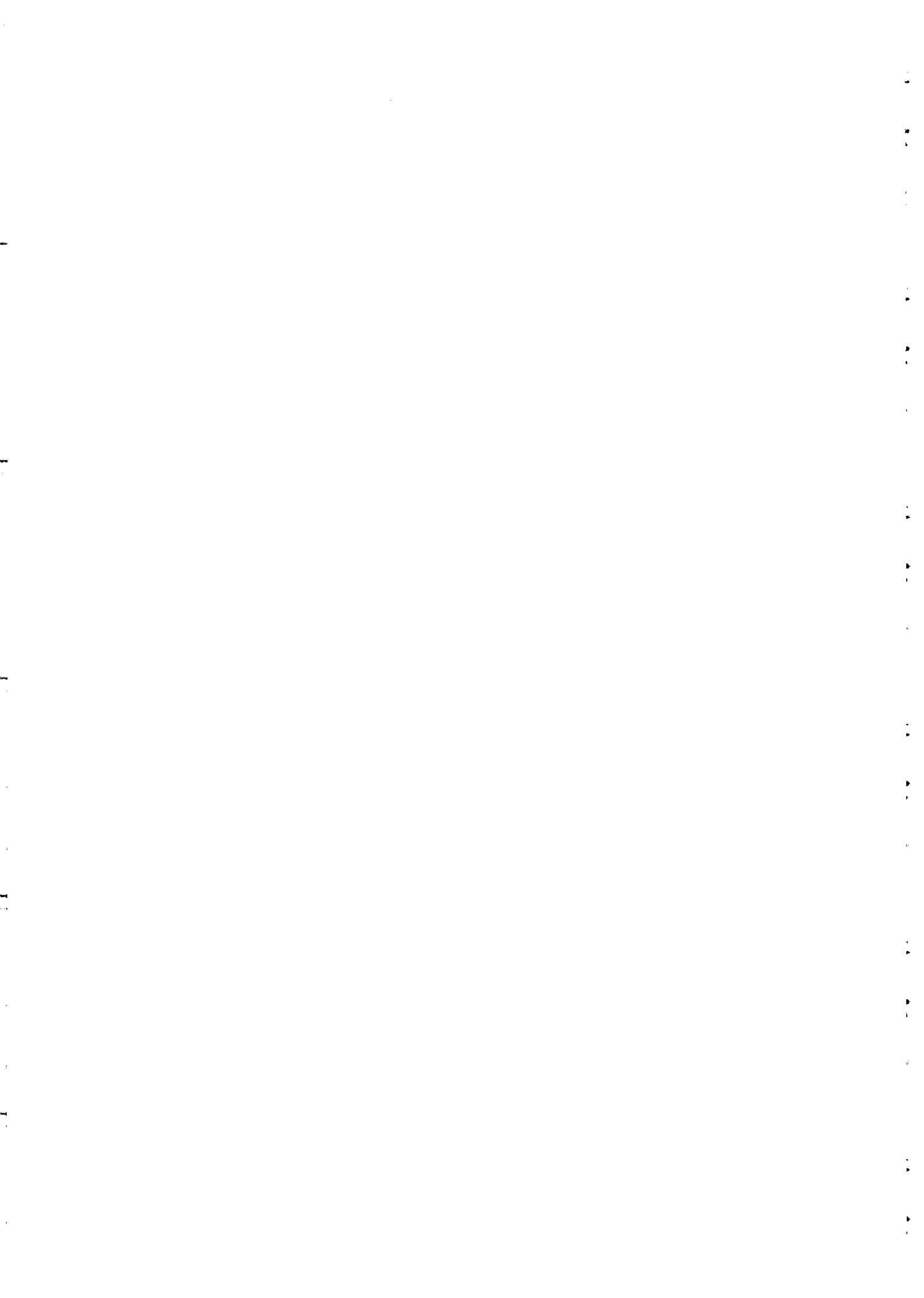
13 March - 14 April 2000

*Miramare - Trieste, Italy*

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*Computational Chain*

**G.B. Bruna**  
**FRAMATOME**  
**Paris, France**





UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION  
INTERNATIONAL ATOMIC ENERGY AGENCY  
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS  
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE



H4.SMR/1056-39

**WORKSHOP ON NUCLEAR REACTION DATA AND NUCLEAR REACTORS:  
PHYSICS, DESIGN AND SAFETY**

**23 February - 27 March 1998**

**Miramare - Trieste, Italy**

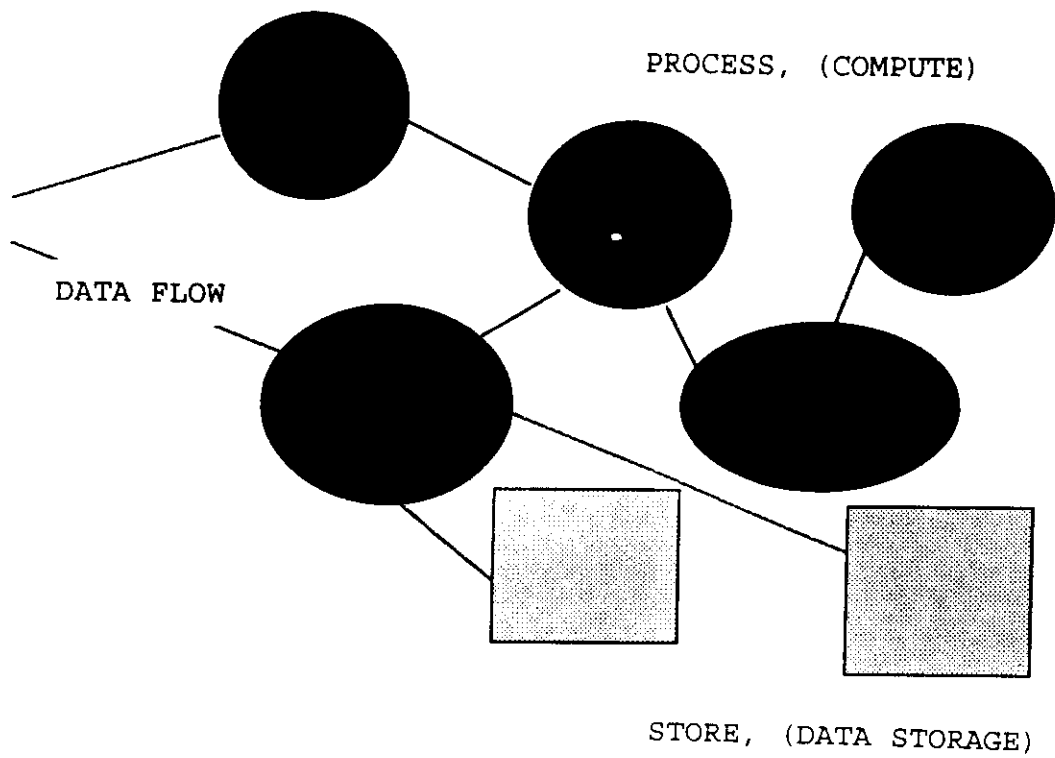
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***Computational Chain***

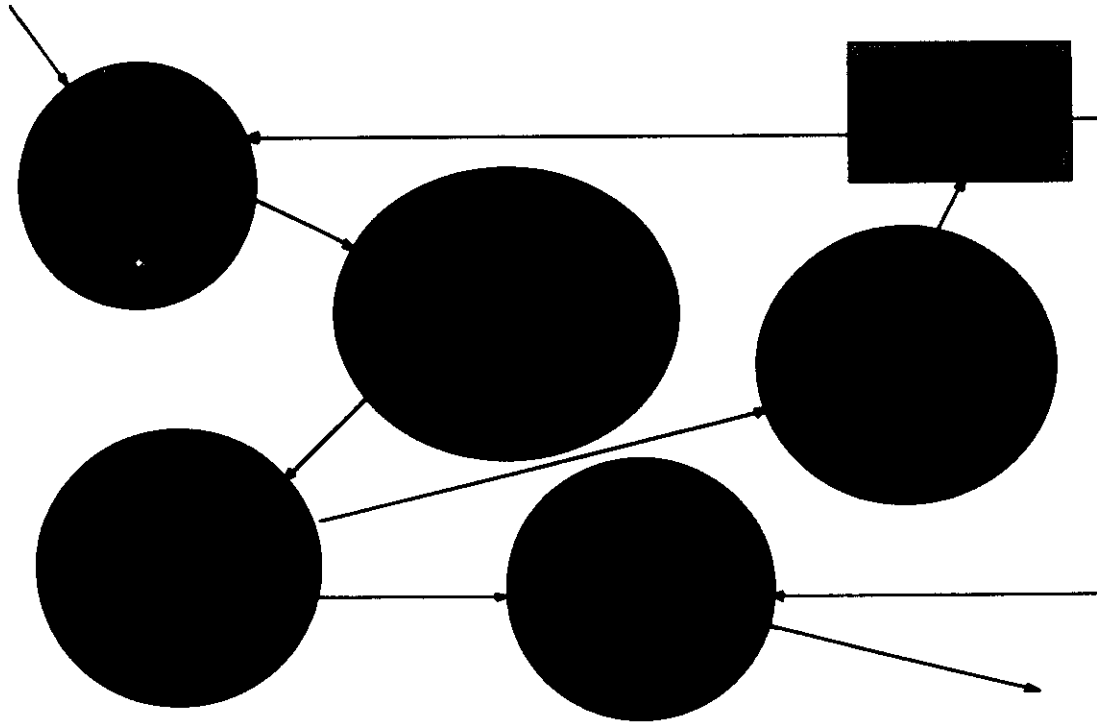
**G.B. Bruna  
FRAMATOME  
92084 Paris  
France**

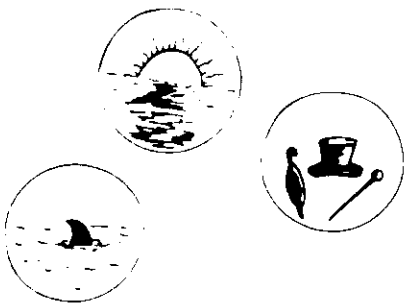
***ADVANCED COMPUTATIONAL CHAIN***

***A MODERN ADVANCED COMPUTATIONAL CHAIN HAS TO BE MODULAR, IN ORDER TO ALLOW SEPARATING THE PROCESS AND TO PERMIT AN EASY MAINTENANCE AND UP-DATING: EACH MODULE SHOULD EXECUTE A SINGLE OPERATION***

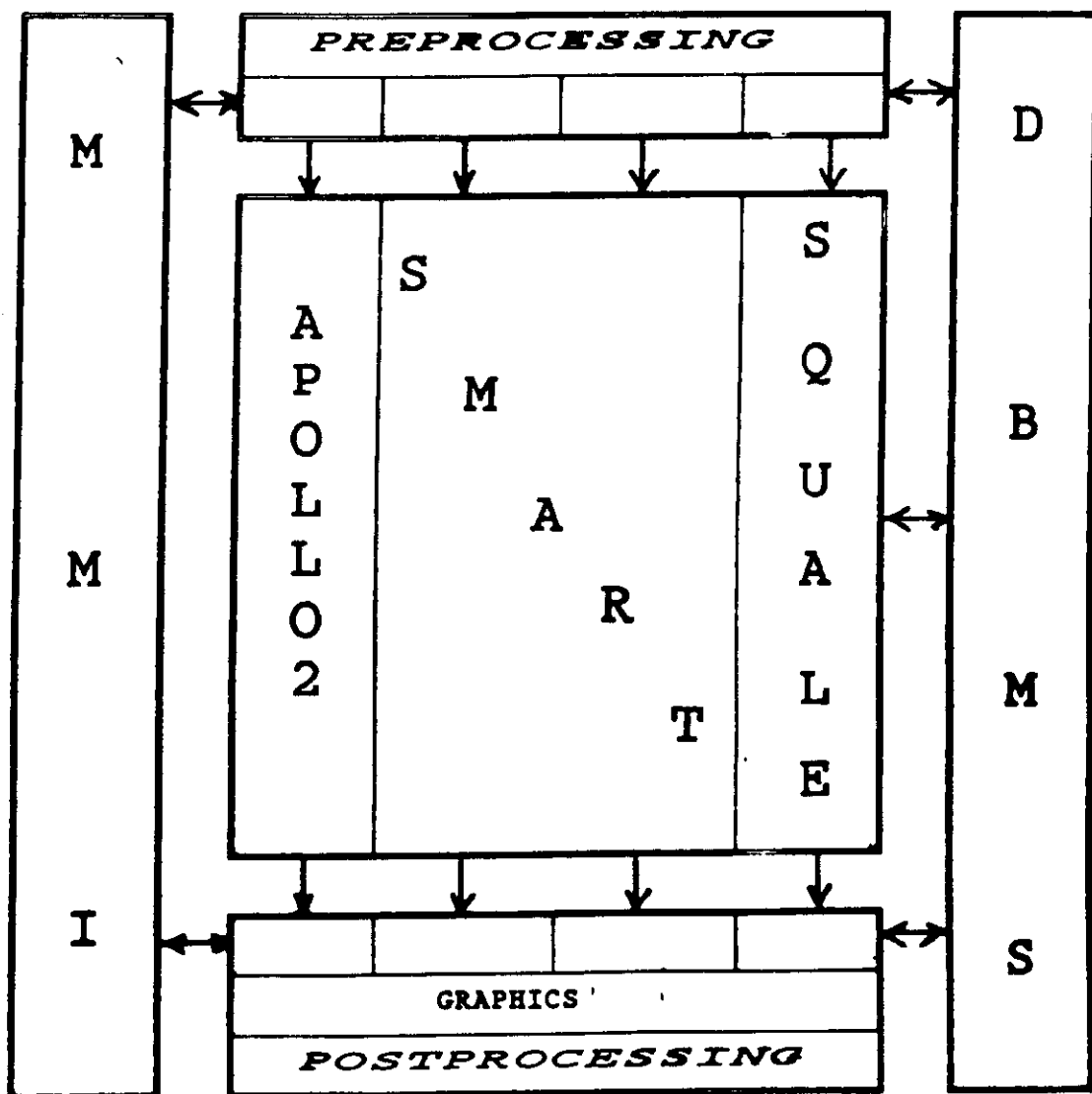


*ADVANCED COMPUTATIONAL CHAIN STRUCTURED  
ANALYSIS (S. A.)*





# STRUCTURED DESIGN



M M I : Man Machine Interface  
 D B M S : Data Base Management System



## **COMPUTATIONAL TOOLS:**

### **- X. S. GENERATION:**

#### **LIBRARIES**

**TRANSPORT CELL - ASSEMBLY MODULES**

**HOMOGENISATION - EQUIVALENCE ROUTINES**

**PROJECT FEW GROUP LIBRARY GENERATION  
MODULES**

**X. S. TABULATION ROUTINES**

### **- DESIGN MODULES**

### **- VALIDATION AND QUALIFICATION MODULES**

### **- SENSITIVITY ANALYSIS MODULES**

### **- INHOMOGENEOUS EQUATION COMPUTATION MODULES**

### **- KINETICS COMPUTATION ROUTINES**

### **- FAST RUNNING COMPUTATIONAL MODULES FOR ON- LINE CALCULATION**

### **- ADJUSTMENT ROUTINES**

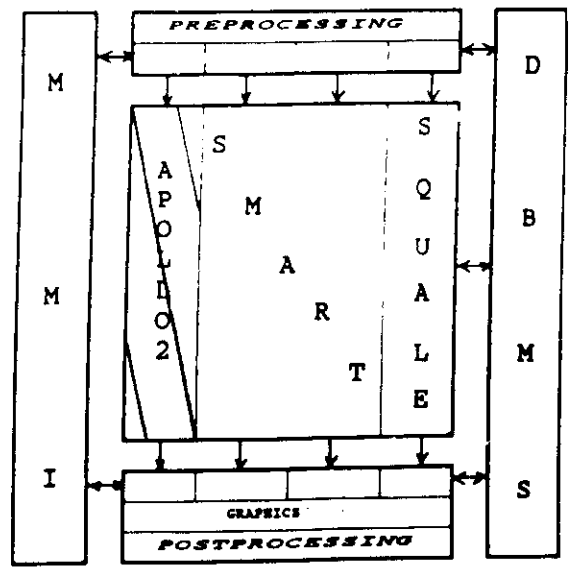




***DESIGN COMPUTATIONAL TOOLS***

***THREE DIMENSIONAL DIFFUSION CODES WITH:***

- ***X. S. INTERPOLATION DEVICES***
- ***ADVANCED FLUX COMPUTATION ROUTINES***
- ***XE AND SAMARIUM EVOLUTION COMPUTATION TOOLS***
- ***PIN-WISE POWER COMPUTATION TOOLS***
- ***BURN-UP BREEDING PROCESS DESCRIPTION ROUTINES***
- ***CONTROL ROD POSITION SIMULATION ROUTINES***
- ***EXPLOITATION AND STORAGE DEVICES***



***APOLLO II: AN ADVANCED MULTITASK TRANSPORT TWO DIMENSION CELL CODE***



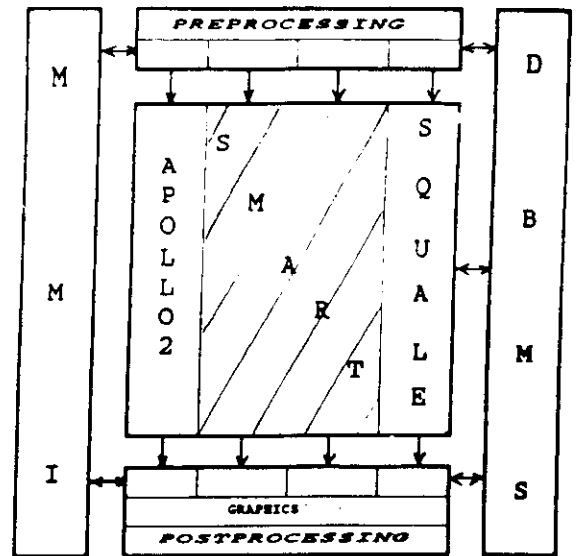
***APOLLO - II IS AN ADVANCED MULTITASK TRANSPORT  
TWO DIMENSIONS MODULE. IT COMPUTES:***

- FEW - GROUP X.S. FOR DISCRETE DIFFUSION  
CALCULATIONS***
- TWO - GROUP X.S., DISCONTINUITY FACTORS AND PIN -  
WISE POWER TABLES FOR ADVANCED NODAL  
COMPUTATIONS***

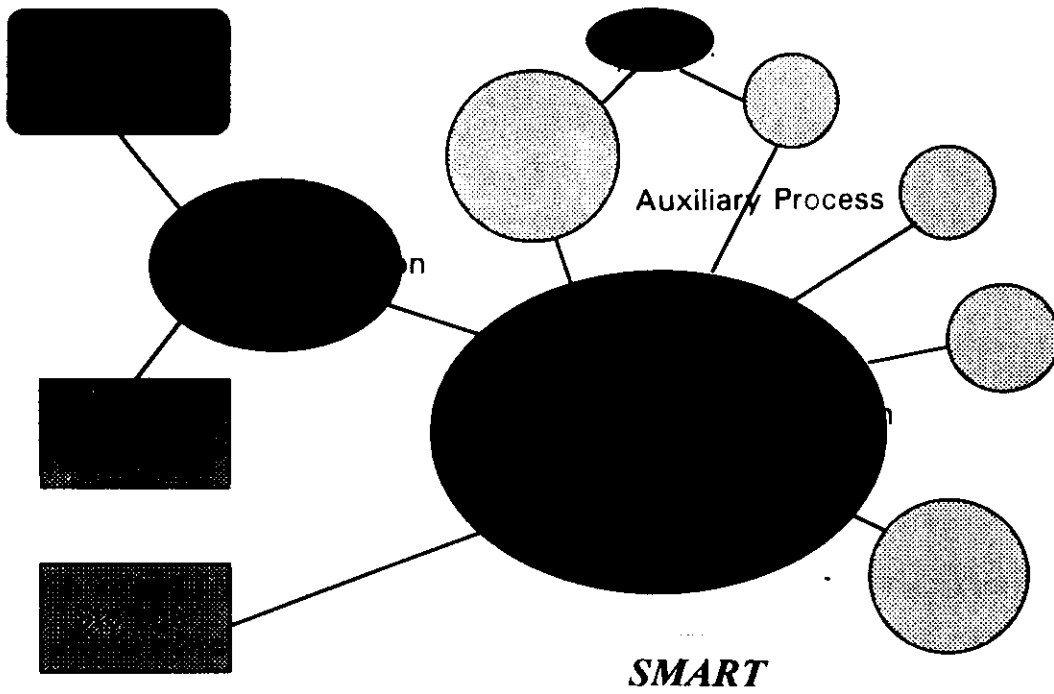


***APOLLO - 2 MAIN FEATURES:***

- ***JEF - 2 BASIC DATA LIBRARY***
- ***CELL, ASSEMBLY AND CLUSTER X,Y AND HEXAGONAL GEOMETRY***
- ***MULTIREGION, MULTIGROUP SELF-SHIELDING CALCULATIONS***
- ***TRANSPORT 2D EXACT AND MULTICELL FLUX CALCULATIONS***
- ***ADVANCED BURN-UP CALCULATIONS***
- ***X.S. COLLAPSING AND HOMOGENISATION***
- ***X.S. EQUIVALENCE***
- ***X.S. TABLE GENERATION***
- ***X.S. EDITING AND STORAGE***



***SMART: A MULTITASK MODULAR SYSTEM FOR PROJECT CALCULATIONS, BASED ON A 3D NODAL DIFFUSION DISCRETISATION***

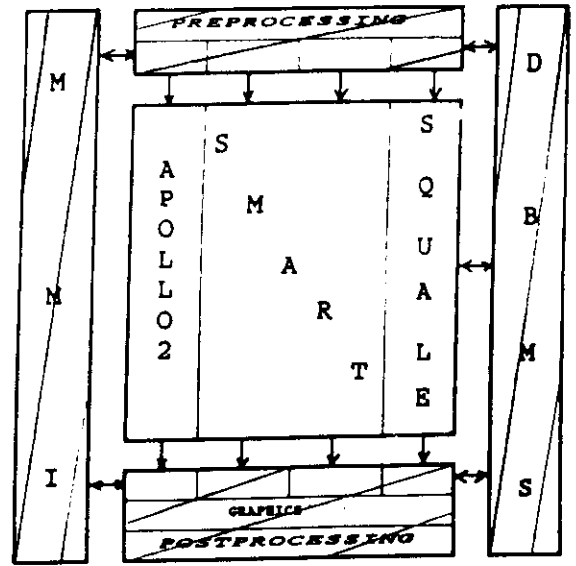
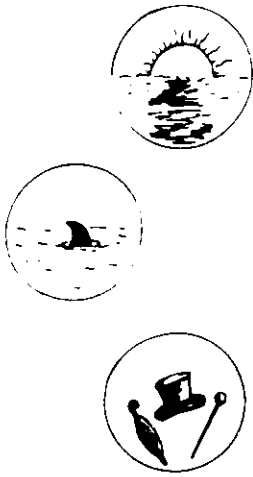




## ***DESIGN COMPUTATIONAL TOOLS***

### ***THREE DIMENSIONAL DIFFUSION CODES WITH:***

- X. S. INTERPOLATION DEVICES***
- ADVANCED FLUX COMPUTATION ROUTINES***
- XE AND SAMARIUM EVOLUTION COMPUTATION TOOLS***
- PIN-WISE POWER COMPUTATION TOOLS***
- BURN-UP BREEDING PROCESS DESCRIPTION ROUTINES***
- CONTROL ROD POSITION SIMULATION ROUTINES***
- EXPLOITATION AND STORAGE DEVICES***

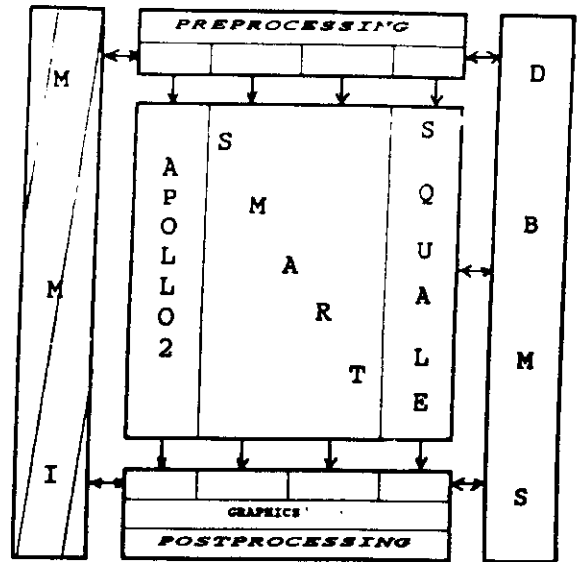
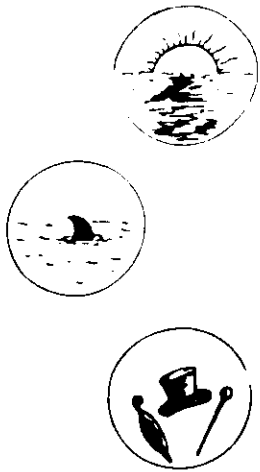


## ***ERGONOMY***

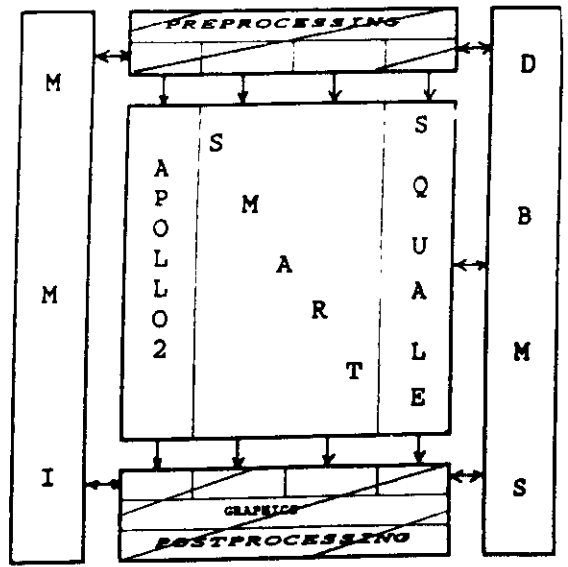
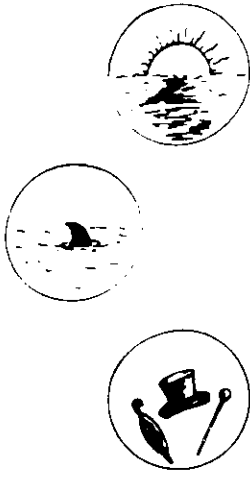
- ***M. M. I. (MAN - MACHINE INTERFACE SYSTEM)***
- ***PRE-PROCESSING***
- ***POST PROCESSING***
- ***D. B. M. S., (DATA BASE MANAGEMENT SYSTEM)***



STRUCTURED DESIGN

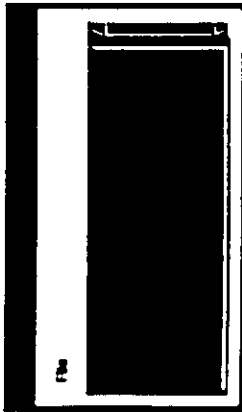


*M. M. I. (MAN - MACHINE INTERFACE SYSTEM)*



- *PRE-PROCESSING*

- *POST PROCESSING*



**Contexte d'étude**

projet :  
 type d'étude :  
 type de reacteur :  
 nom de la branche :  
 numero de branche :

---

etude courante :  
 etat de l'étude :  
 plan courant :  
 etat du plan :

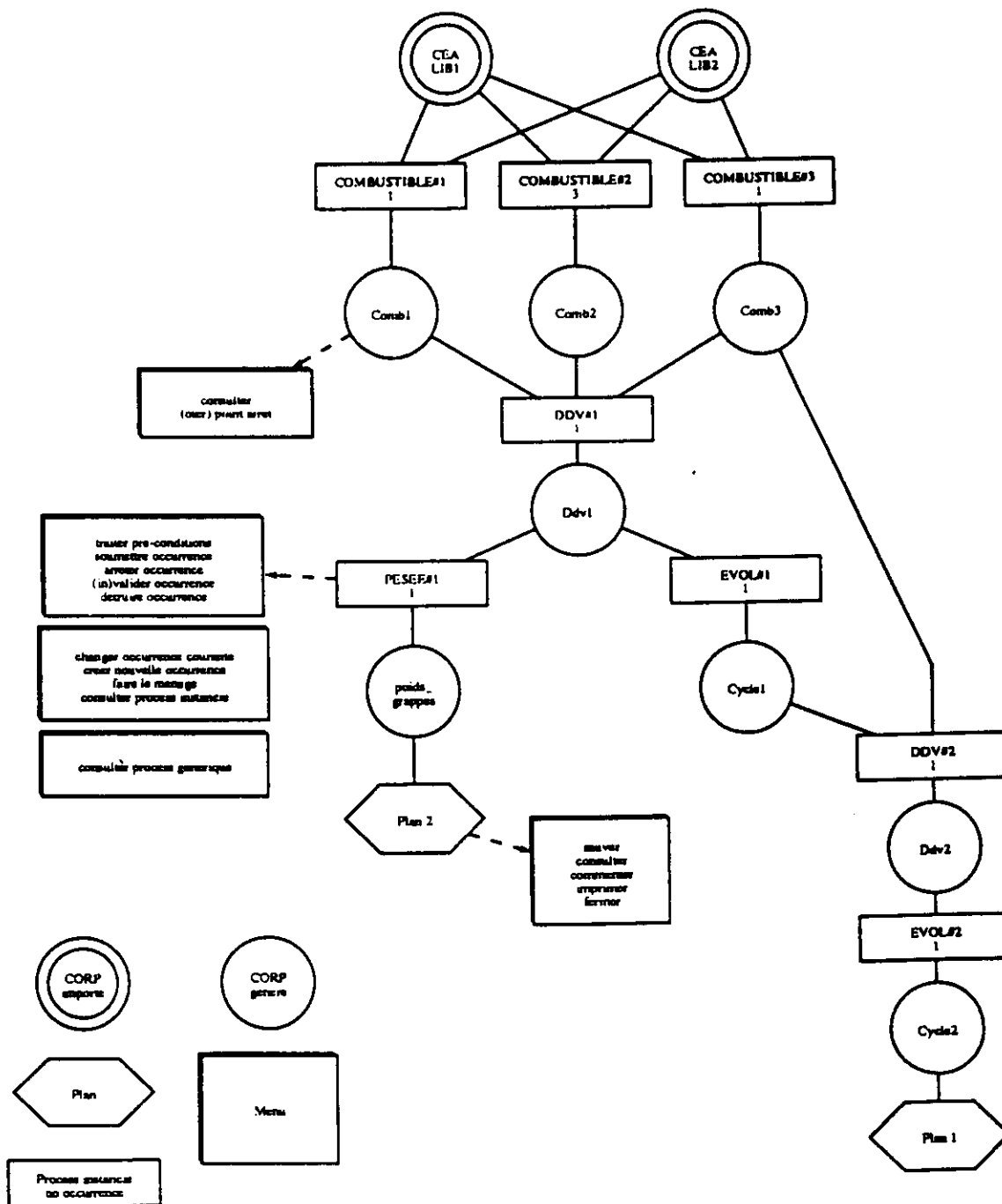
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Couleurs  
 Legende  
 Centrage

Echelle  
 ◀ lecteur 12  
 lecteur 1  
 lecteur 2

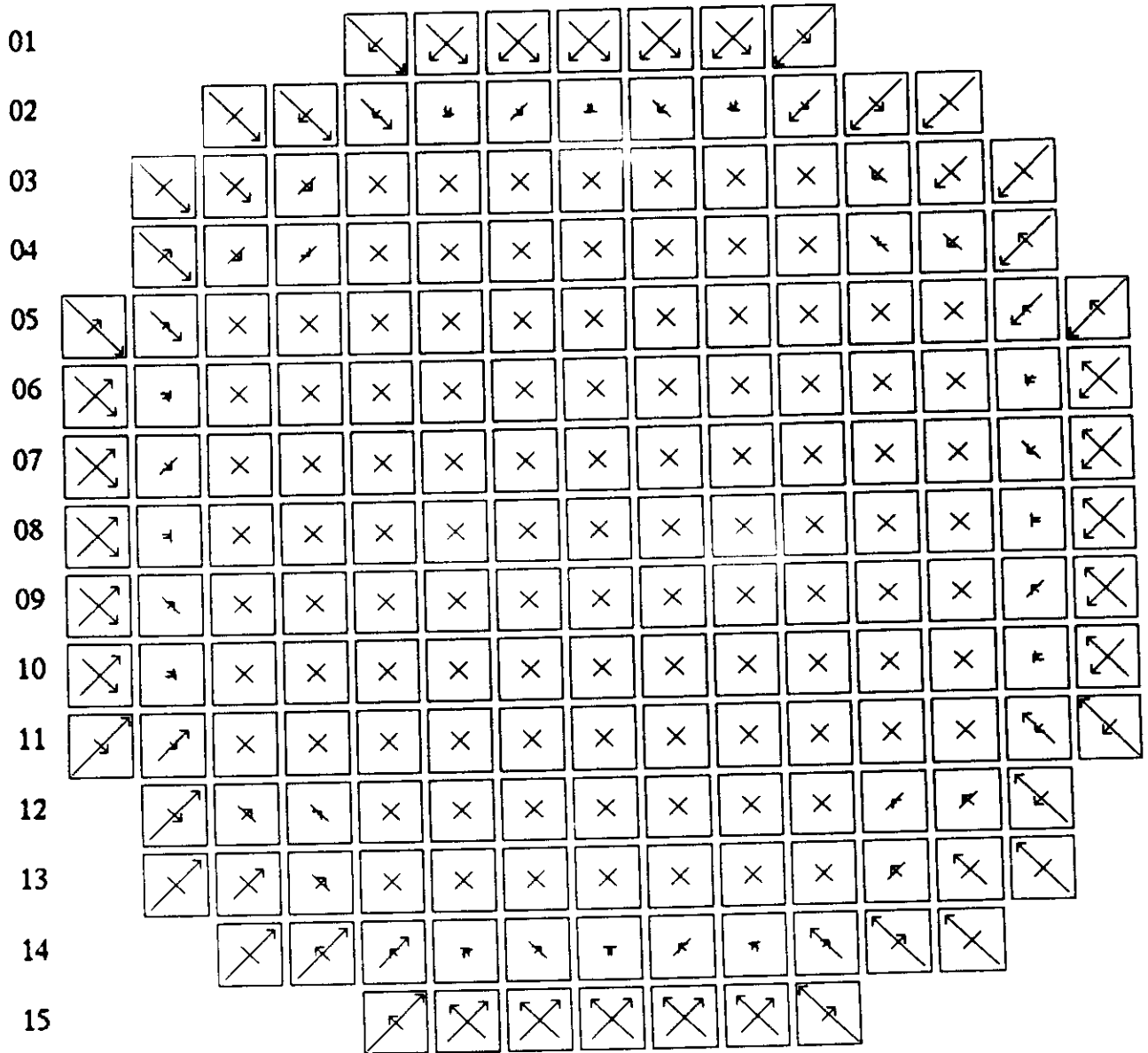
Outil Etude Tache Options Aide

Over  
 Destroy  
 Ouvrir  
 Fermer  
 Imprimer  
 Consulter  
 Documenter





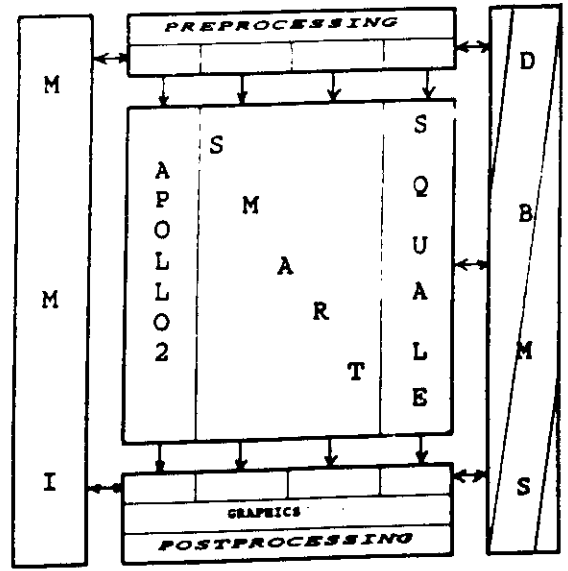
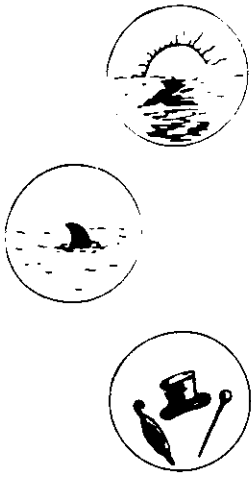
R P N M L K J H G F E D C B A



RESTART ET EDITION COEUR C (puissance)

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
01					1 0421	1 1265	1 1868	1 1866	1 1868	1 1265	1 0421				
02		0 9501	1 2384	1 3672	1 0407	1 1207	1 1731	1 1207	1 0407	1 3672	1 2384	0 9501			
03	0 9501	0 9680	1 0716	1 0814	1 1423	1 1117	1 1586	1 1117	1 1423	1 0814	1 0716	0 9680	0 9501		
04		1 2384	1 0716	1 0529	1 1490	1 1250	1 1816	1 1461	1 1816	1 1250	1 1490	1 0529	1 0716	1 2384	
05	1 0421	1 3672	1 0814	1 1490	1 1264	1 1920	1 1621	1 2015	1 1621	1 1920	1 1264	1 1490	1 0814	1 3672	1 0421
06	1 1265	1 0407	1 1423	1 1250	1 1920	1 1669	1 2150	1 1822	1 2150	1 1669	1 1920	1 1250	1 1423	1 0407	1 1265
07	1 1868	1 1207	1 1117	1 1816	1 1621	1 2150	1 1887	1 2225	1 1887	1 2150	1 1621	1 1816	1 1117	1 1207	1 1868
08	1 1866	1 1731	1 1586	1 1461	1 2015	1 1822	1 2225	1 1952	1 2225	1 1822	1 2015	1 1461	1 1586	1 1731	1 1866
09	1 1868	1 1207	1 1117	1 1816	1 1621	1 2150	1 1887	1 2225	1 1887	1 2150	1 1621	1 1816	1 1117	1 1207	1 1868
10	1 1265	1 0407	1 1423	1 1250	1 1920	1 1669	1 2150	1 1822	1 2150	1 1669	1 1920	1 1250	1 1423	1 0407	1 1265
11	1 0421	1 3672	1 0814	1 1490	1 1264	1 1920	1 1621	1 2015	1 1621	1 1920	1 1264	1 1490	1 0814	1 3672	1 0421
12		1 2384	1 0716	1 0529	1 1490	1 1250	1 1816	1 1461	1 1816	1 1250	1 1490	1 0529	1 0716	1 2384	
13		0 9501	0 9680	1 0716	1 0814	1 1423	1 1117	1 1586	1 1117	1 1423	1 0814	1 0716	0 9680	0 9501	
14		0 9501	1 2384	1 3672	1 0407	1 1207	1 1731	1 1207	1 0407	1 3672	1 2384	0 9501			
15					1 0421	1 1265	1 1868	1 1866	1 1868	1 1265	1 0421				

RESTART ET EDITION COEUR C (pic)



- D. B. M. S., (DATA BASE MANAGEMENT SYSTEM)



## ***INFORMATION HANDLING AND STORAGE***

***INFORMATION MUST BE STORED IN A VERY STRUCTURED AND COMPACT WAY, IN ORDER TO HALLOW A PRACTICAL AND USEFUL HANDLING AND GUARANTEE ITS LONG TIME PROTECTION AND SAFE-GUARD IN TIME ACCORDINGLY TO Q. A. PRESCRIPTIONS***

***INFORMATION HAS TO BE STRUCTURED IN COMPACT PACKAGES, , EACH OF THEM CONTAINING HOMOGENEOUS INFORMATION***

***EVERY PACKAGE MUST BE ADDRESSED IN A REPERTORY, WHICH HAVE TO CONTAIN THE RELEVANT INFORMATION OF EACH PACKAGE, IN ORDER TO ALLOW AN EASY SEARCH***

***REPERTORY HAS TO BE STORED IN A PROTECTED AREA OF THE MEMORY AND HAS TO BE GOVERNED BY AN ADAPTED SYSTEM***

***STORAGE OF THE BULK OF INFORMATION HAS TO BE MADE ELSEWHERE***

***PROJECT COMPUTATIONAL CHAIN QUALIFICATION***

- VIA CRITICAL AND MOCK-UP EXPERIMENTS***
- VIA EXPLOITATION OF THE OPERATIONAL EXPERIENCE***

**POINT-WISE POWER DISTRIBUTION ANALYSIS:**

- **CAMELEON EXPERIMENT, VARIOUS CONTROL ROD MATERIALS AND GEOMETRIES IN A UO<sub>2</sub> LATTICE, WITH A CENTRAL 17 X 17 ASSEMBLY;**
- **EPICURE EXPERIMENT, THREE ZONED MOX ASSEMBLY IN A UO<sub>2</sub> LATTICE, WITH WATER HOLES;**
- **GEDEON EXPERIMENT: DEPLETION OF SEVERAL GD<sub>2</sub>O<sub>3</sub> PINS IN A UO<sub>2</sub> SLAB LATTICE**

**FULL QUALIFICATION OF THE MOX COMPUTATIONAL OPTIONS:**

- **REACTIVITY VERSUS CELL MOCK-UP EXPERIMENTS**
- **POINT-WISE POWER DISTRIBUTIONS VERSUS VARIOUS CRITICAL EXPERIMENTS, (BATTELLE, MELODIE, EPICURE)**
- **ACTIVITIES VERSUS INCORE MEASUREMENTS**

***POINT-WISE POWER DISTRIBUTION ANALYSIS***  
***THE CAMELEON EXPERIMENT***

**TRANSPORT and DIFFUSION**  
**INFINITE MEDIUM ASSEMBLY CALCULATIONS**  
**of**  
**PIN POWER DISTRIBUTION**

## **MAIN ITEMS**

- **DEFINITION OF A CALCULATION VERSUS MEASUREMENT ANALYSIS PATTERN**
- **SEARCH FOR TRANSPORT AND DIFFUSION SCHEMES WELL ADAPTED TO CALCULATE EXPERIMENT**
- **STATISTICAL TREATMENT OF RESULTS**

# EXPERIMENTAL ENVIRONMENT

**UO<sub>2</sub> : DIAMETER 7 mm  
ALUMINIUM CLAD AND OVER-CLAD**

**GUIDE-TUBE : ALUMINIUM TUBE THICKNESS 0.3 mm  
INNER DIAMETER 10.1 mm**

**ABSORBER ROD : OUTER DIAMETER 9.7 mm  
SS CLAD  
VARIABLE INNER DIAMETER**

# EXPERIMENTAL ENVIRONMENT

CLEAN CORE ARRANGEMENT

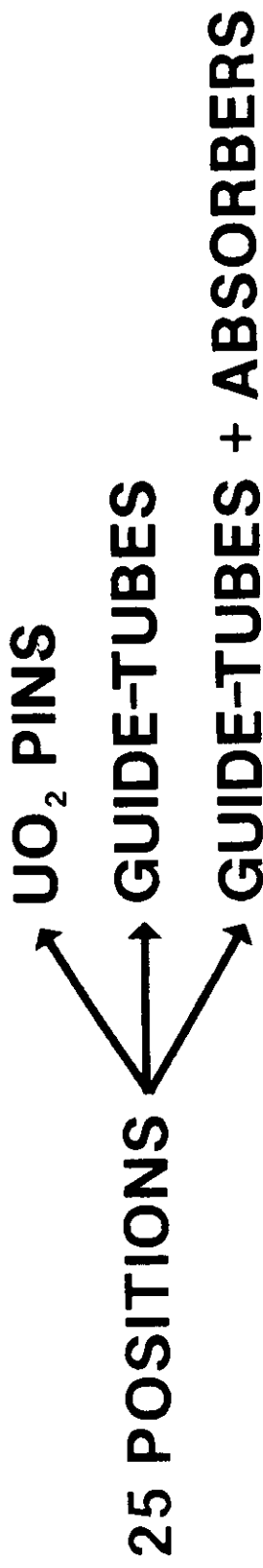
1739 UO<sub>2</sub> PINS

3.5% U<sub>235</sub> ENRICHMENT

SQUARE LATTICE PITCH 1.26 cm

ACTIVE HEIGHT 80 cm

CENTRAL 17 x 17 TEST ZONE :





# EXPERIMENTAL ENVIRONMENT

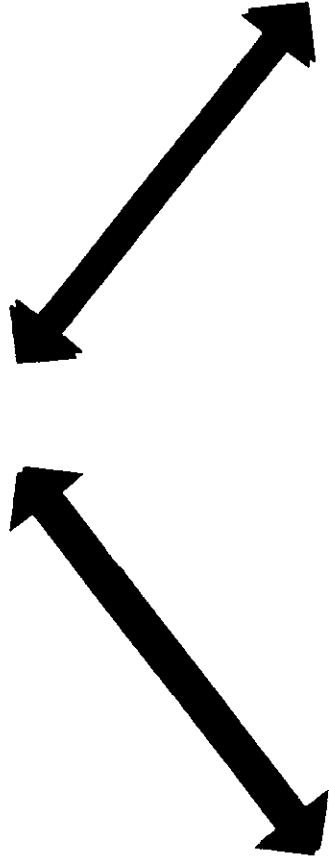
## MEASUREMENT OF RADIAL FISSION RATE DISTRIBUTIONS :

- SELECTION OF MEASURES ON 1/8 CENTRAL TEST ZONE
- AN INTEGRAL GAMMA SPECTROMETRY TECHNIQUE
- THRESHOLD ON GAMMA ENERGY

## UNCERTAINTIES :

- EXPERIMENTAL TECHNIQUE
  - EXPERIMENTAL ASYMMETRY
- 2,2 %

**OVERALL UNCERTAINTY :  $\pm 3\%$  ( $2\sigma$ )**

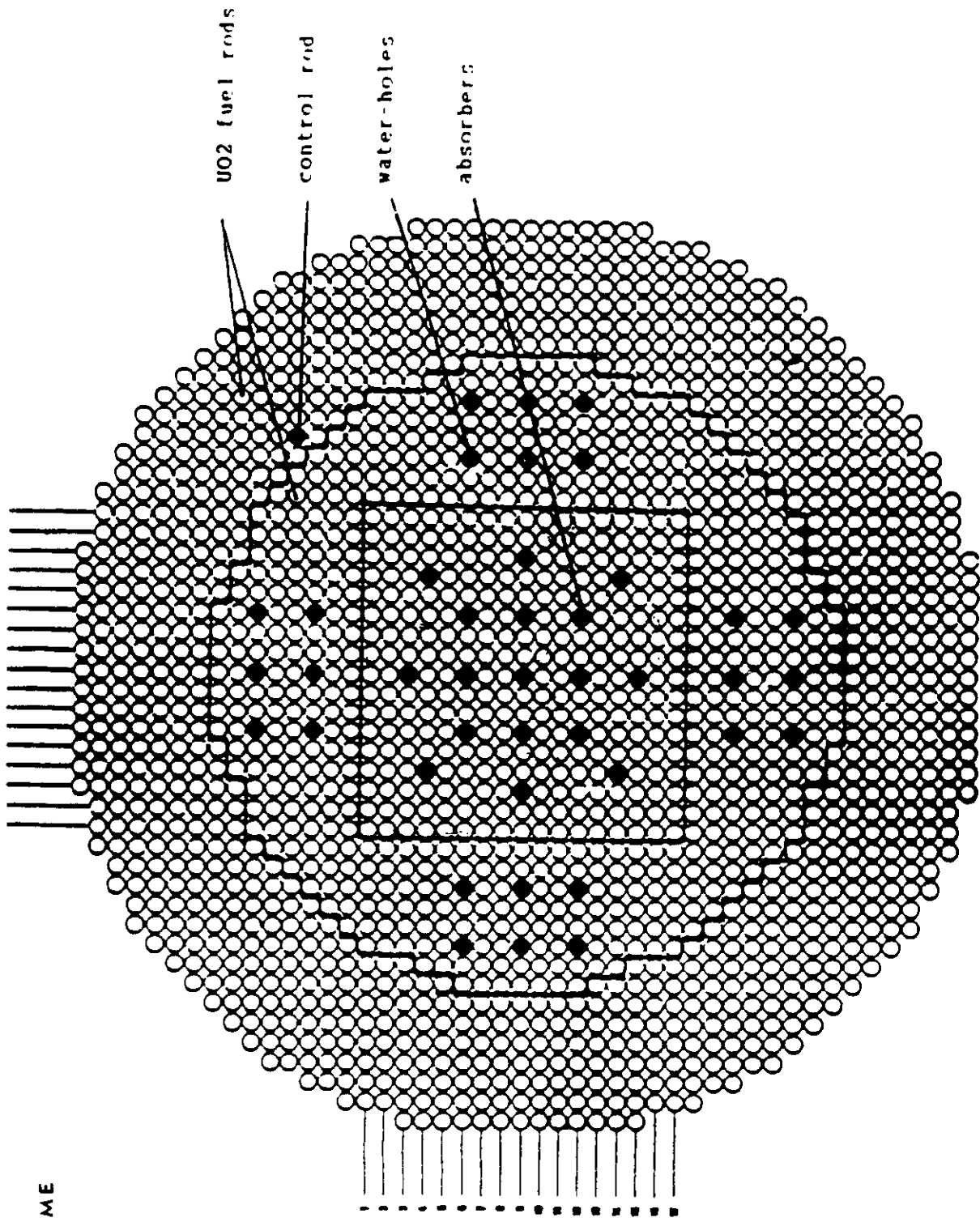


**2.2 %**

**EXPERIMENTAL  
UNCERTAINTY**

**2.0 %**

**COMPARISON  
METHODOLOGY**

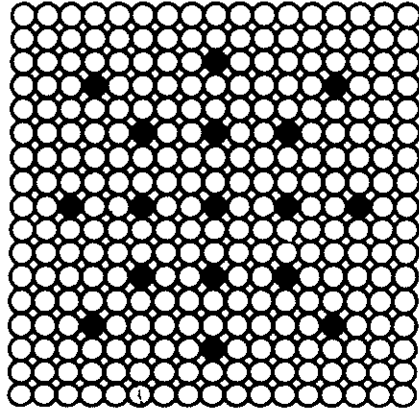
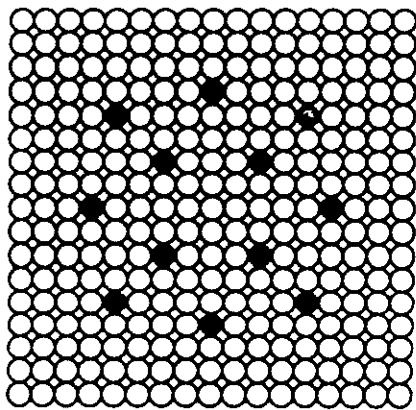
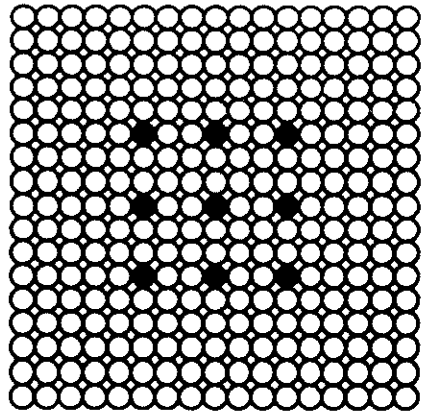
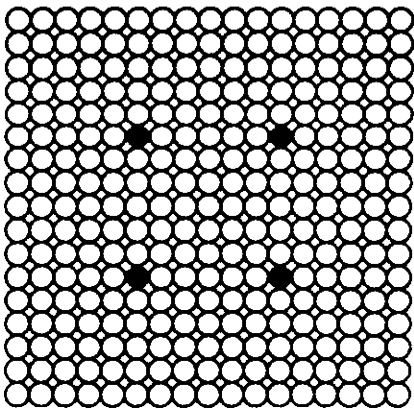
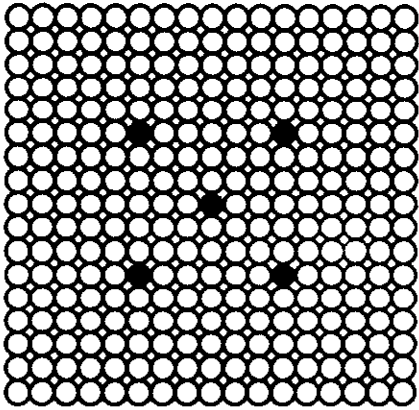




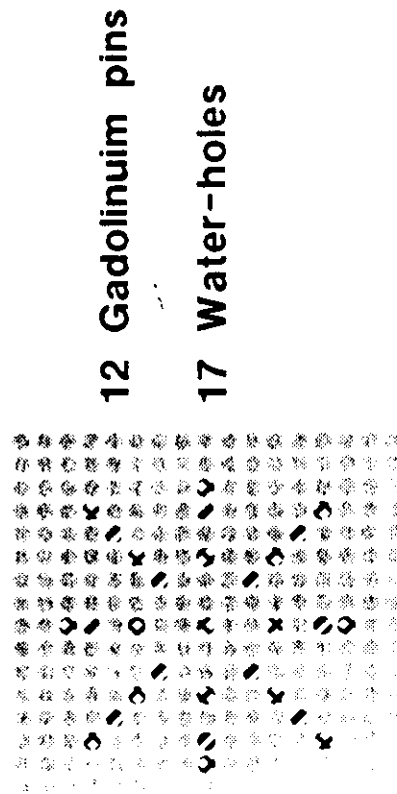
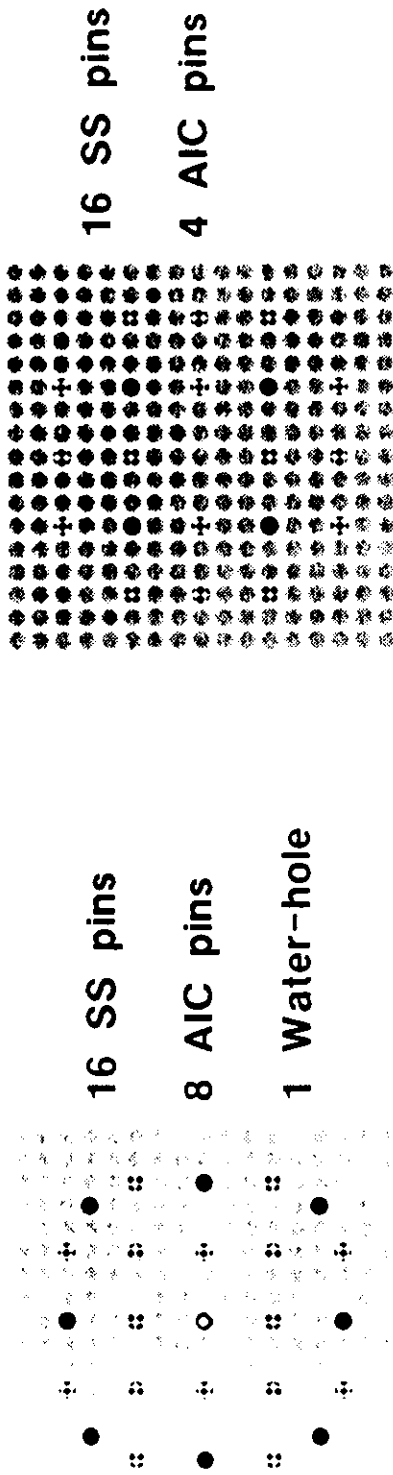
# A SET OF VERY DIFFERENT EXPERIMENTAL CONFIGURATIONS WAS CHOSEN :

- a 4 pin AIC (Silver, Indium, Cadmium) cluster, +
- a 12 pin Pyrex cluster, ▽
- a 17 pin AIC cluster, □
- a 17 pin B,C cluster, △
- a 24 pin, grey, mixed cluster, made of 16 SS and 8 AIC pins, 人
  
- a 9 pin AIC cluster, x
- a 9 pin B,C cluster, ◇
- a 5 pin Pyrex cluster, ▽
- a 20 pin, grey, mixed cluster, made of 16 SS and 4 AIC pins, ▽
- a 12 pin gadolinium cluster, ⊗
- a 12 pin gadolinium cluster in presence of water holes. ⊕

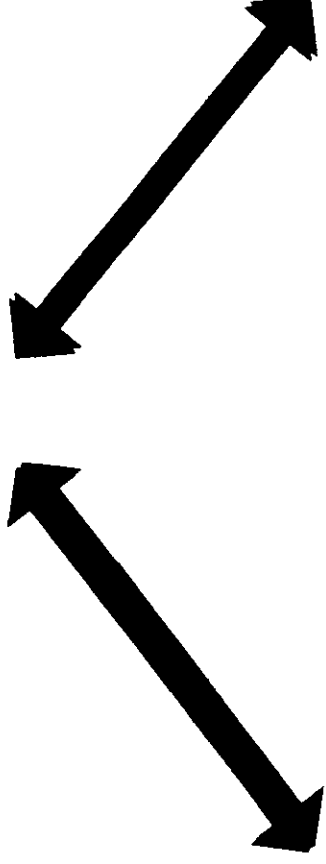
# HOMOGENEOUS CLUSTER CONFIGURATION LAYOUT



# HETEROGENEOUS CLUSTERED CONFIGURATION LAYOUT



**OVERALL UNCERTAINTY :  $\pm 3\%$  ( $2\sigma$ )**

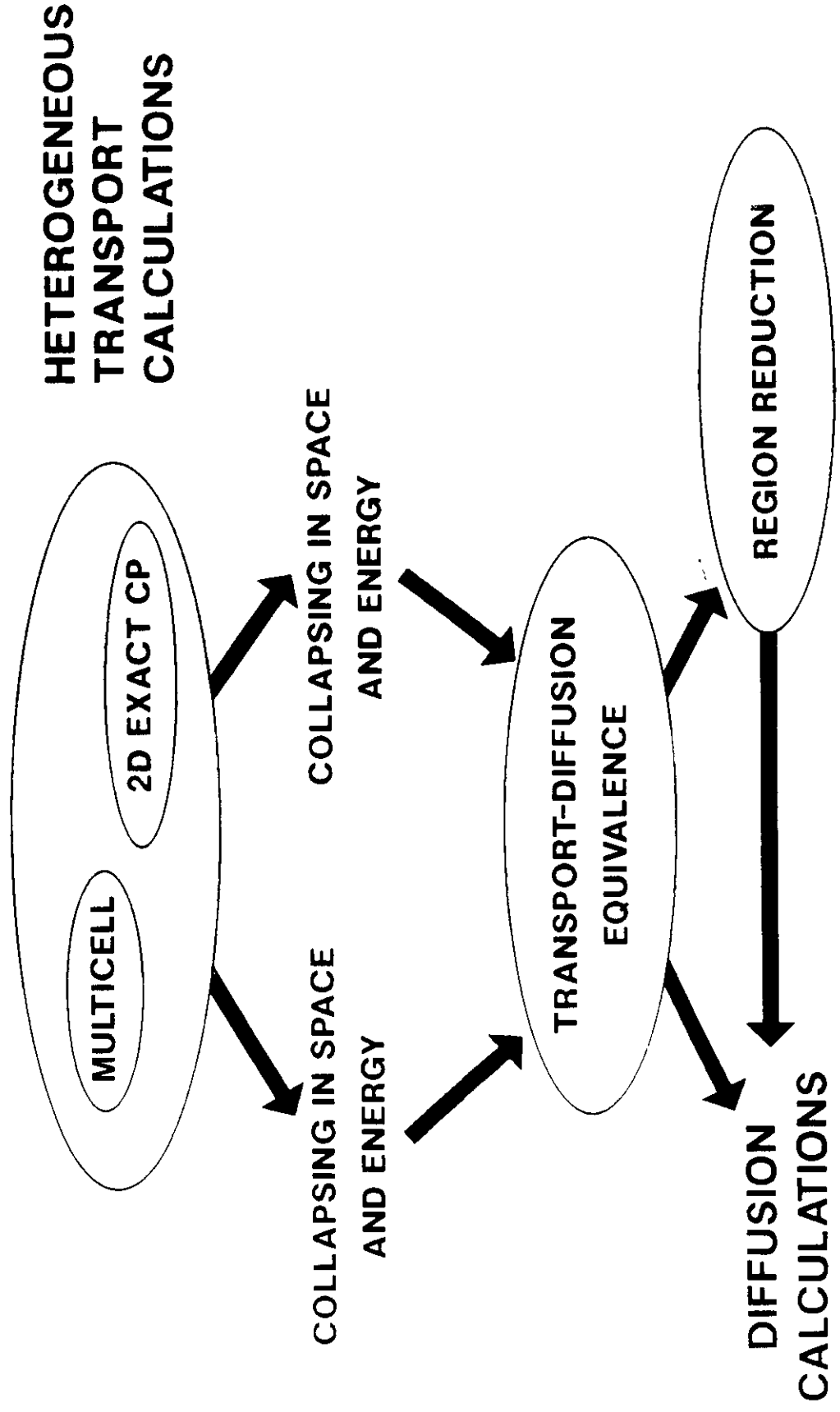


**2.2 %**

**EXPERIMENTAL  
UNCERTAINTY**

**2.0 %**

**COMPARISON  
METHODOLOGY**

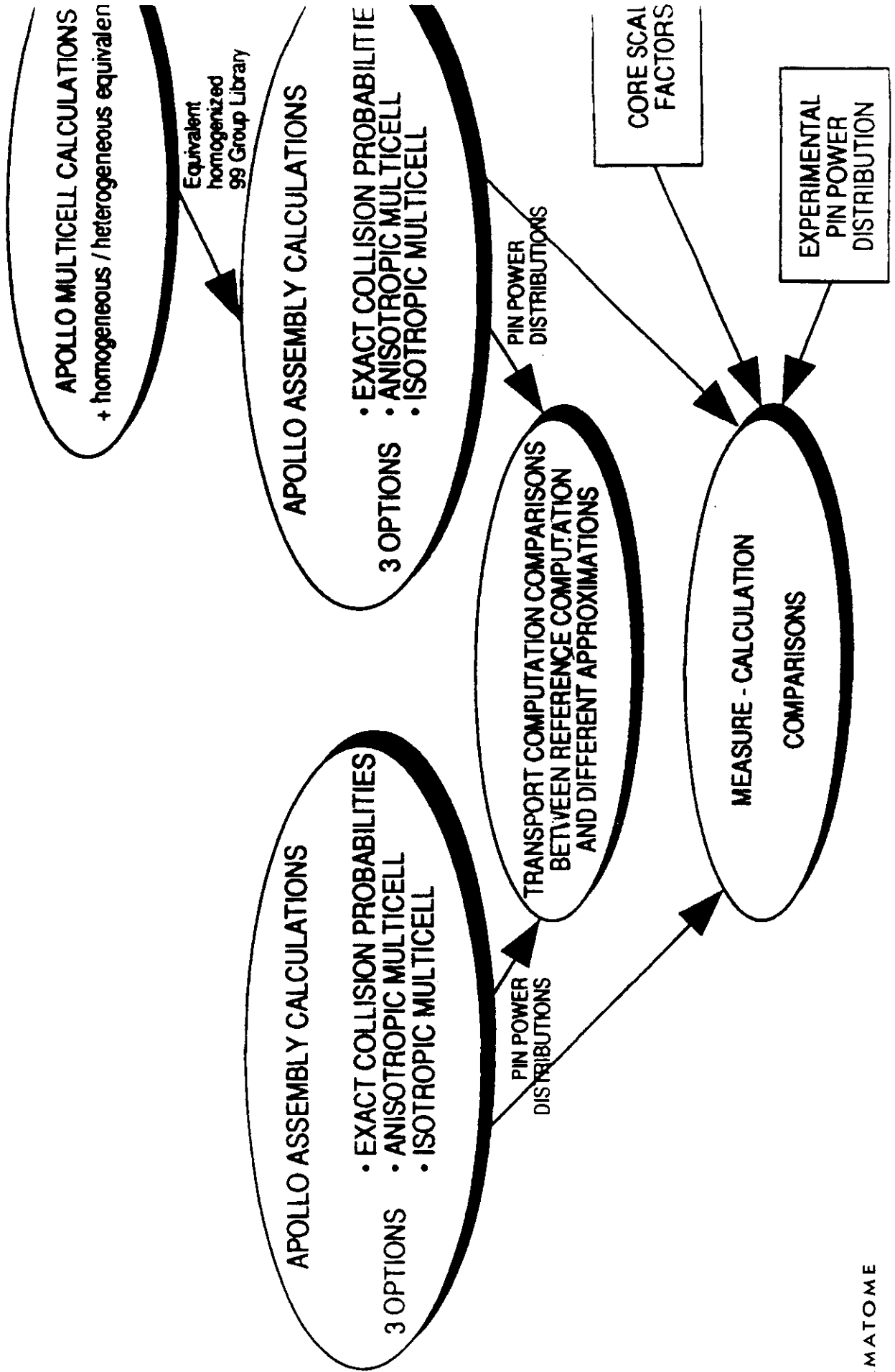


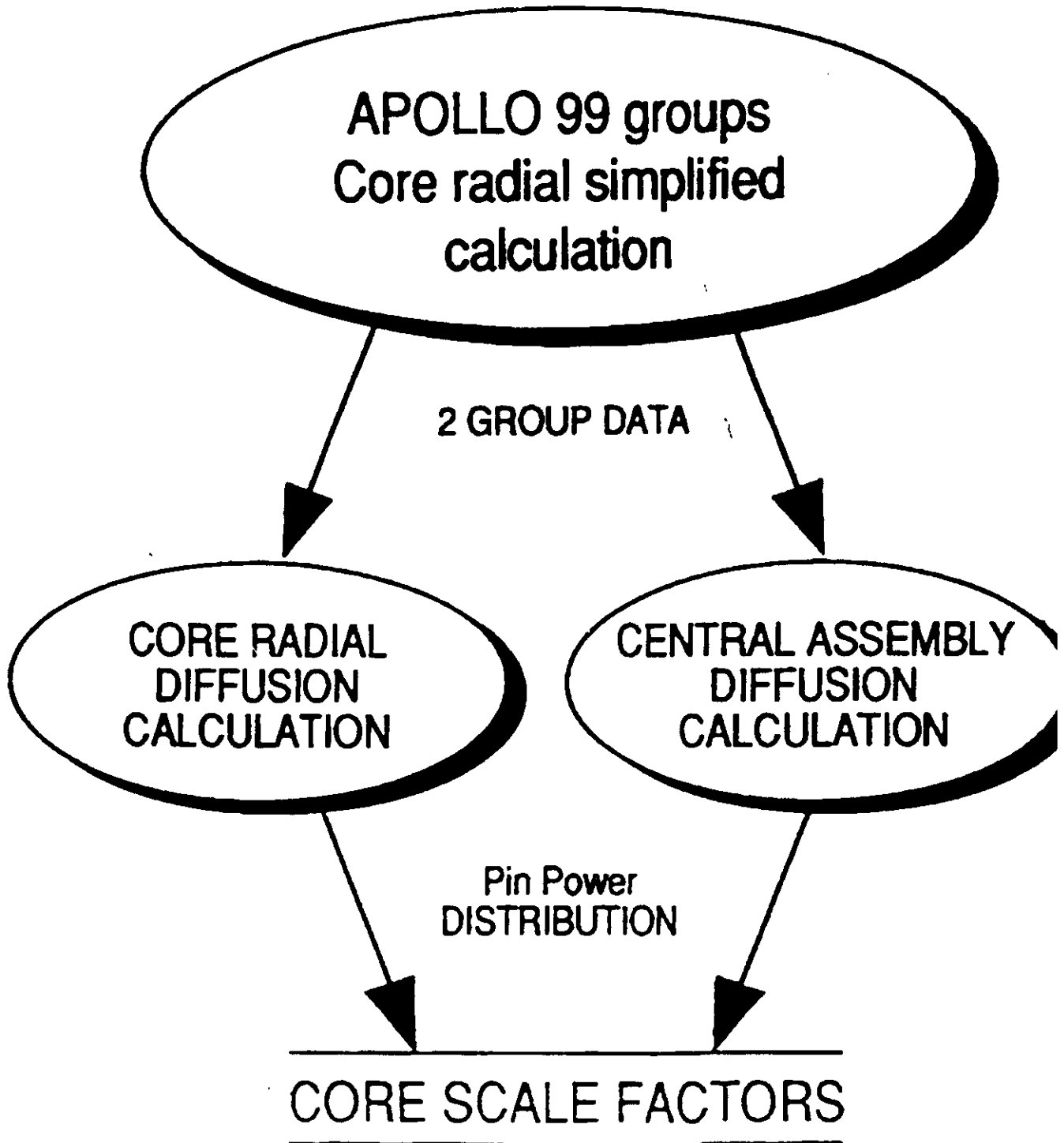


# CENTRAL TEST ZONE CALCULATIONS

# HETEROGENEOUS SCHEME

# HOMOGENEOUS SCHEME





COMPUTATION OF THE CENTRAL TEST ZONE  
FOR EACH CONFIGURATION  
IN TRANSPORT THEORY  
WITH 99 ENERGY GROUPS  
IN INFINITE MEDIUM

CALCULATED  
PIN POWER  
VALUES

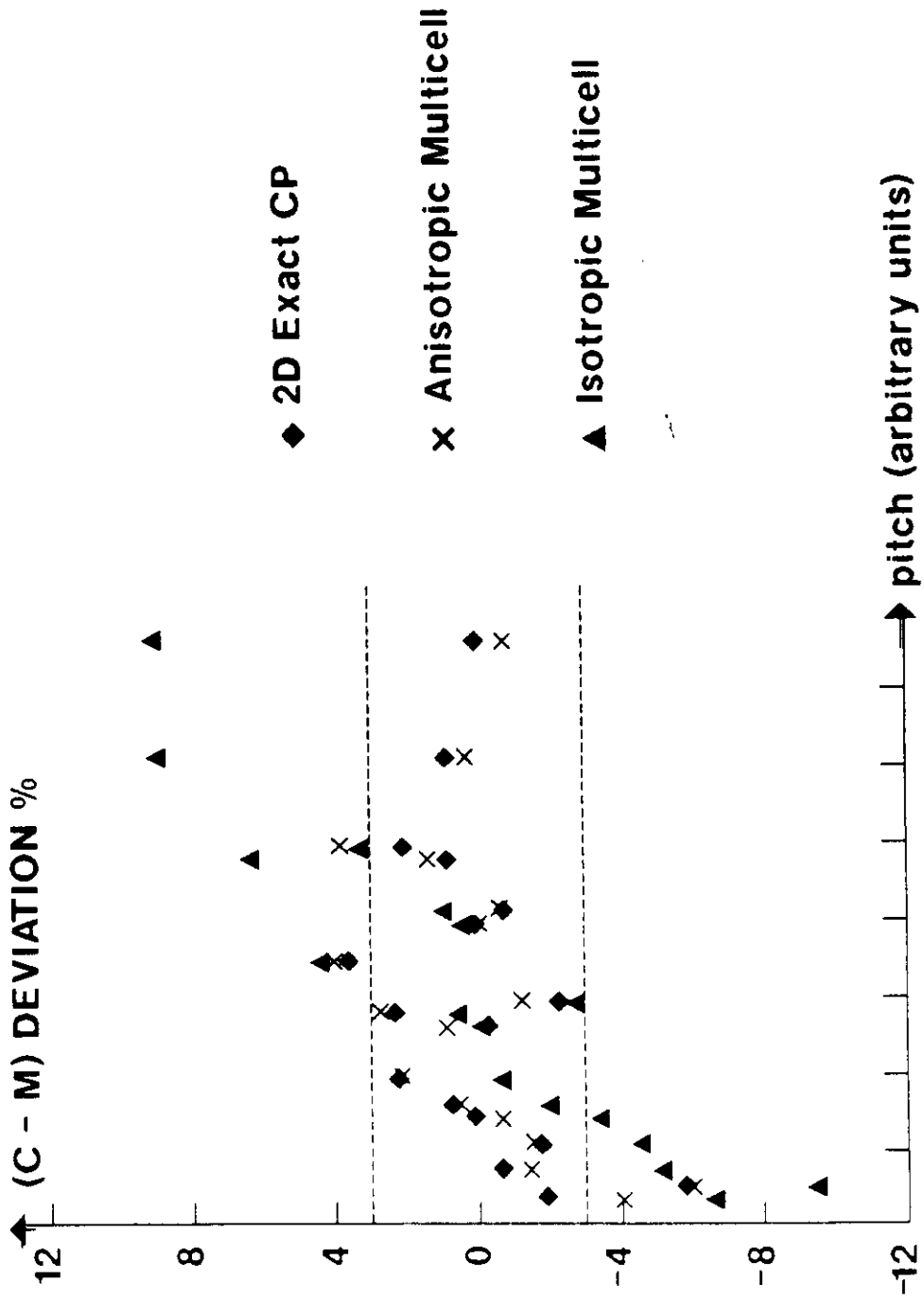
CORE SCALE FACTORS

CALCULATED CORE POWER  
DISTRIBUTION COMPARISONS  
WITH EXPERIMENTAL ONE

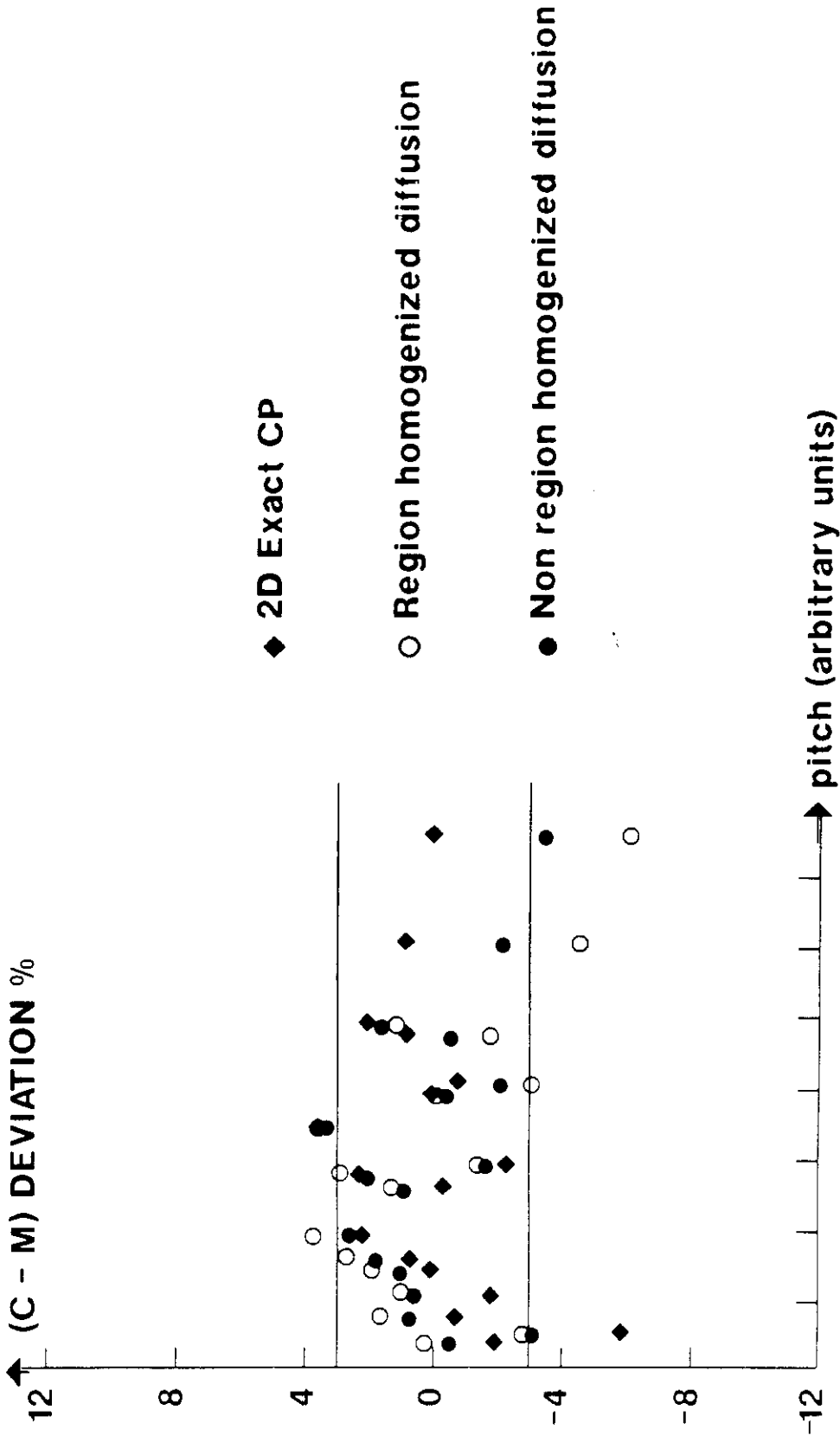
EXPERIMENTAL  
PIN POWER  
VALUES



# (C - M) DEVIATION IN PERCENT FOR THE 17 AIC CONFIGURATION

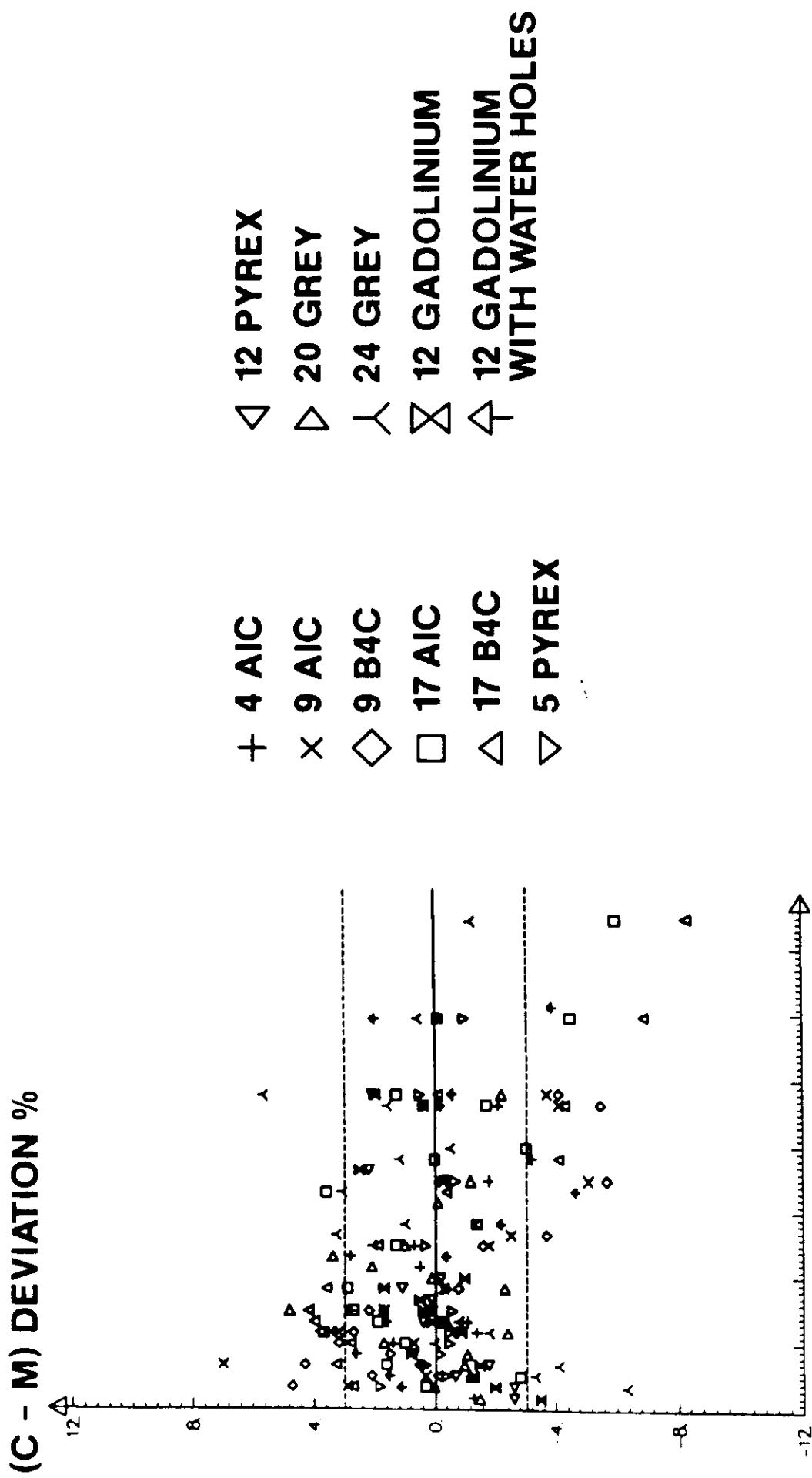


# (C - M) DEVIATION IN PERCENT FOR THE 17 AIC CONFIGURATION

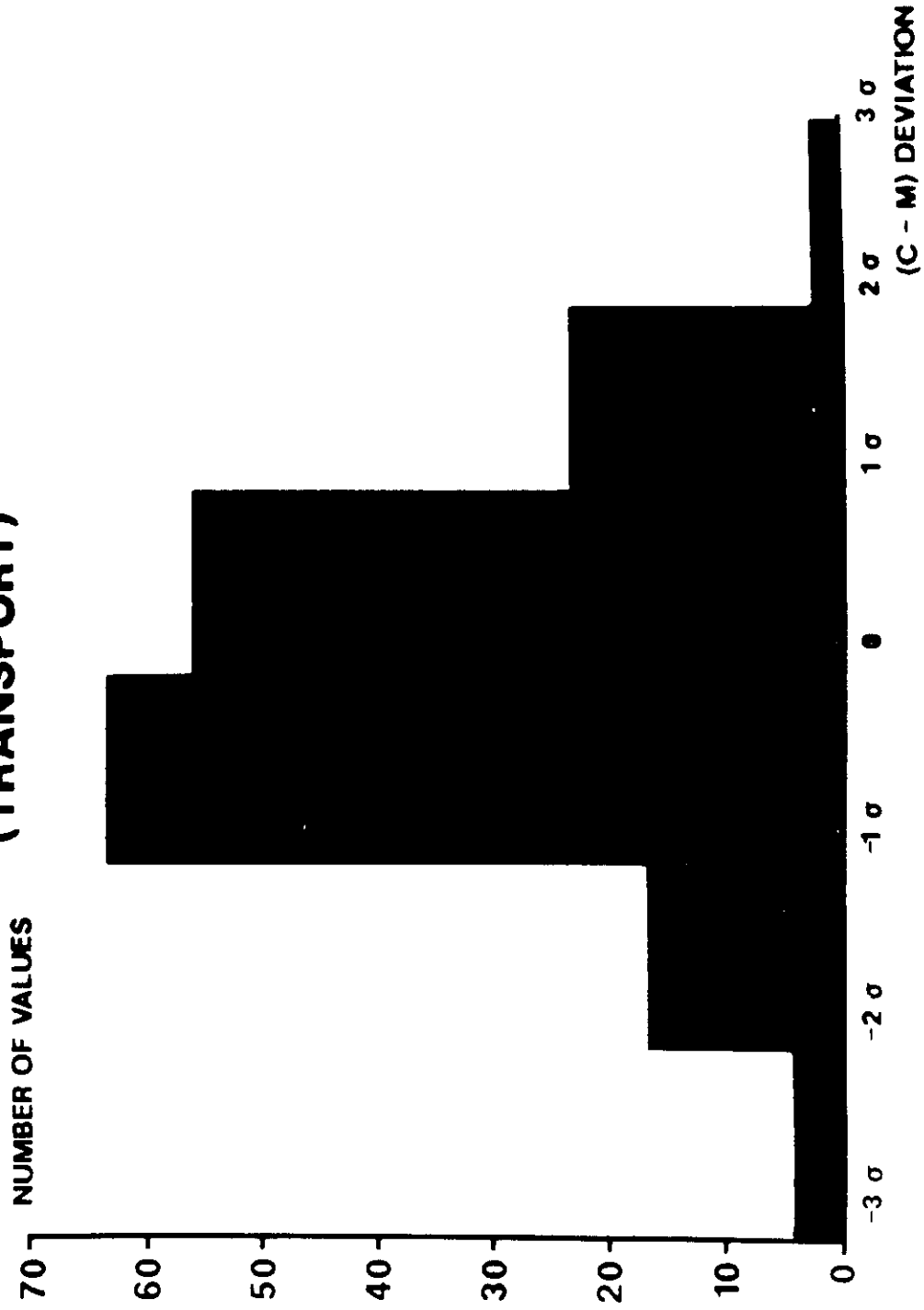


# OVERALL RESULTS

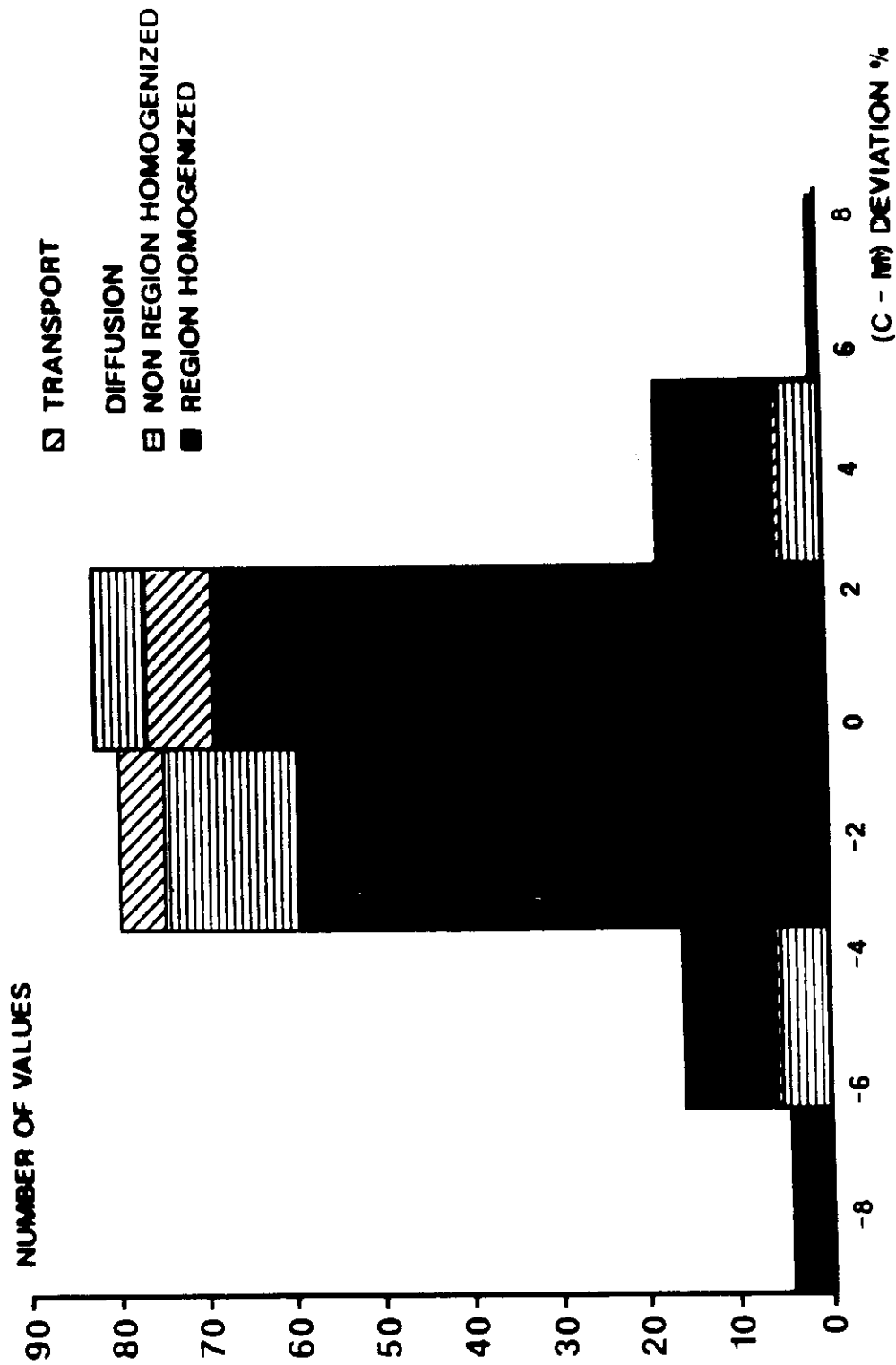
## REGION HOMOGENIZED DIFFUSION CALCULATIONS



# OVERALL RESULTS HISTOGRAM (TRANSPORT)



# OVERALL RESULTS HISTOGRAM



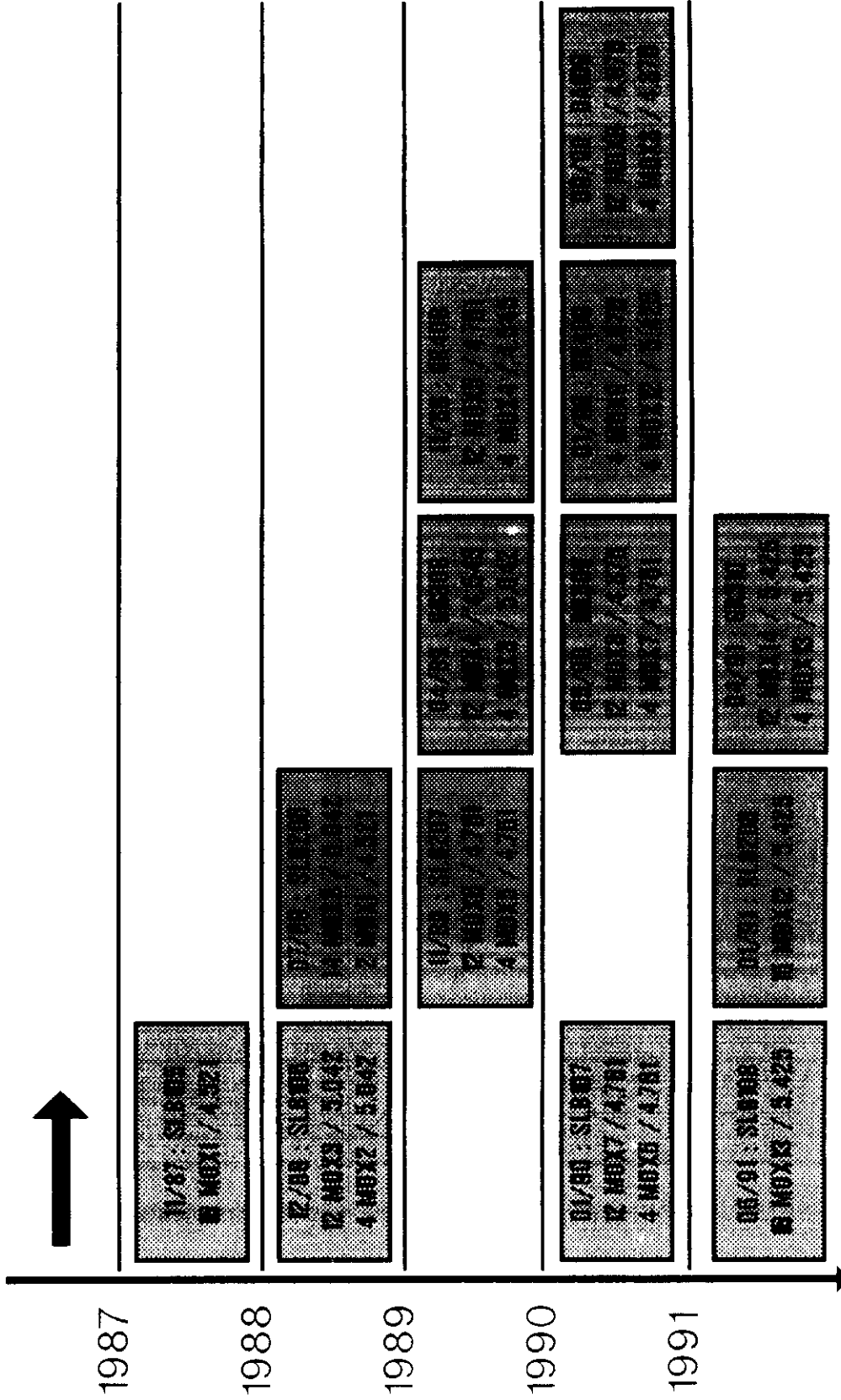


***THE MOX FUEL FEATURES:***

- ***ACTIVITY***
- ***CONTAMINATION***
- ***COOLING***
- ***STORAGE, (VOIDAGE REACTIVITY)***

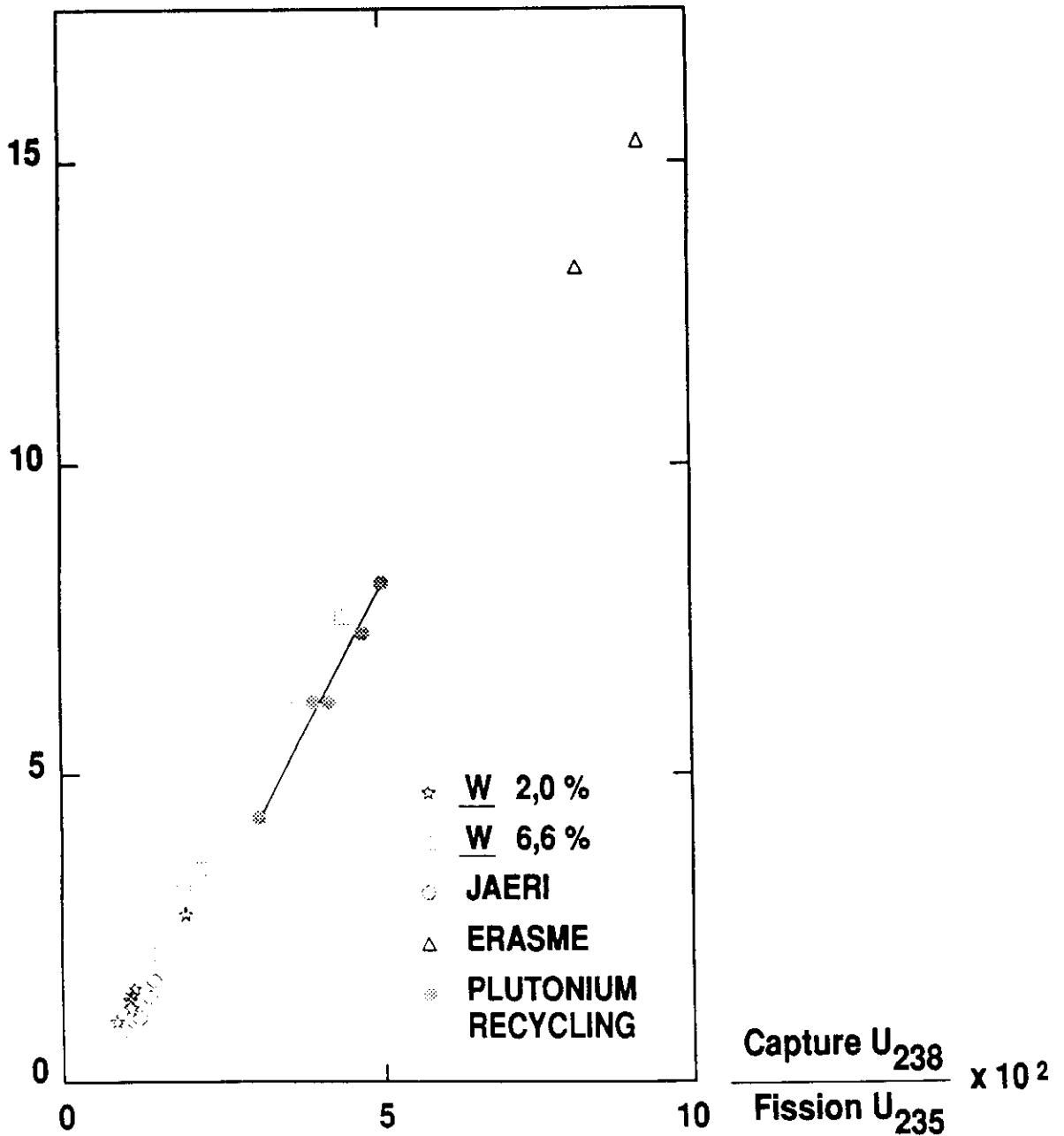
# UP-DATING AND VALIDATION OF A PROJECT MOX COMPUTATIONAL CHAIN

# MOX RELOAD SYNOPSIS

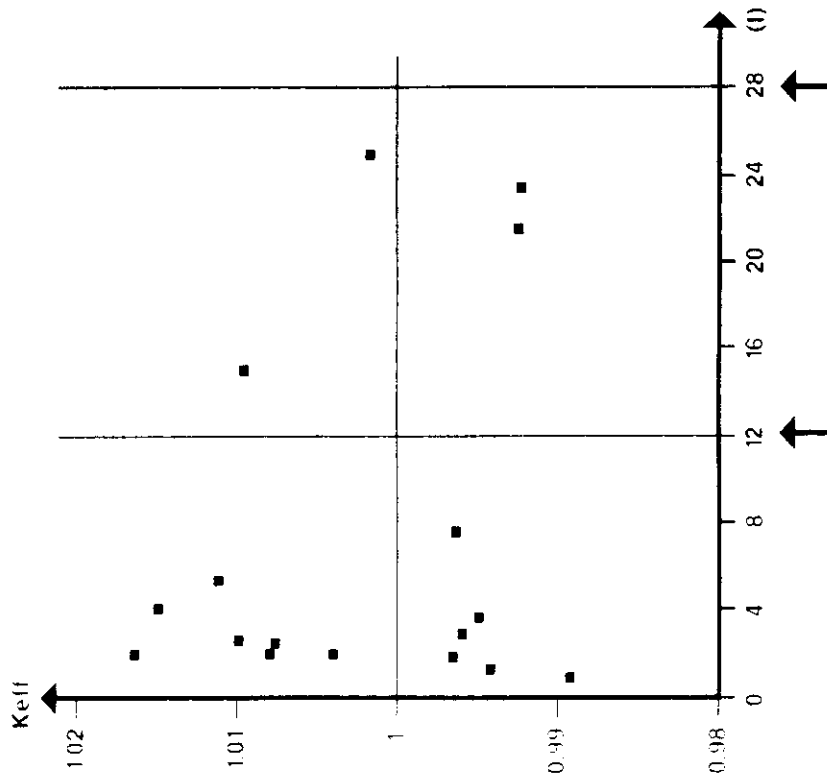


# COMPARISON OF THE PLUTONIUM RECYCLING PHYSICAL CONDITIONS TO THOSE OF THE EXPERIMENTS IN THE SAMPLE

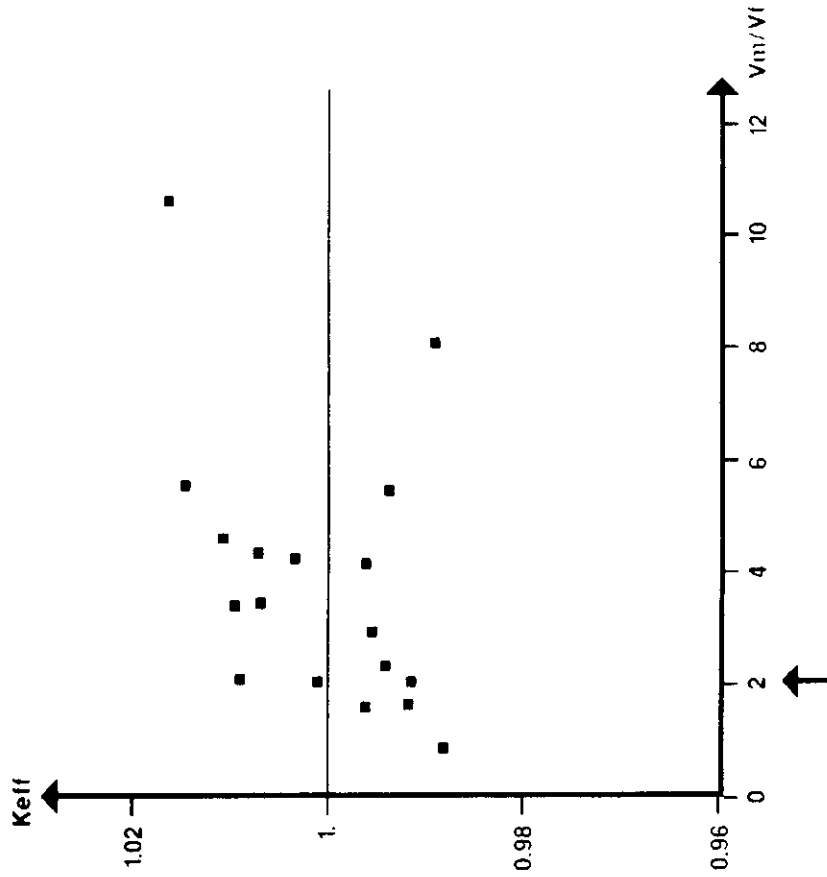
$\frac{\text{Fission } U_{238}}{\text{Fission } U_{235}} \times 10^3$



# Keff VERSUS FAST AND EPITHERMAL TO THERMAL FLUX (CUT-OFF AT 0.625 ev)

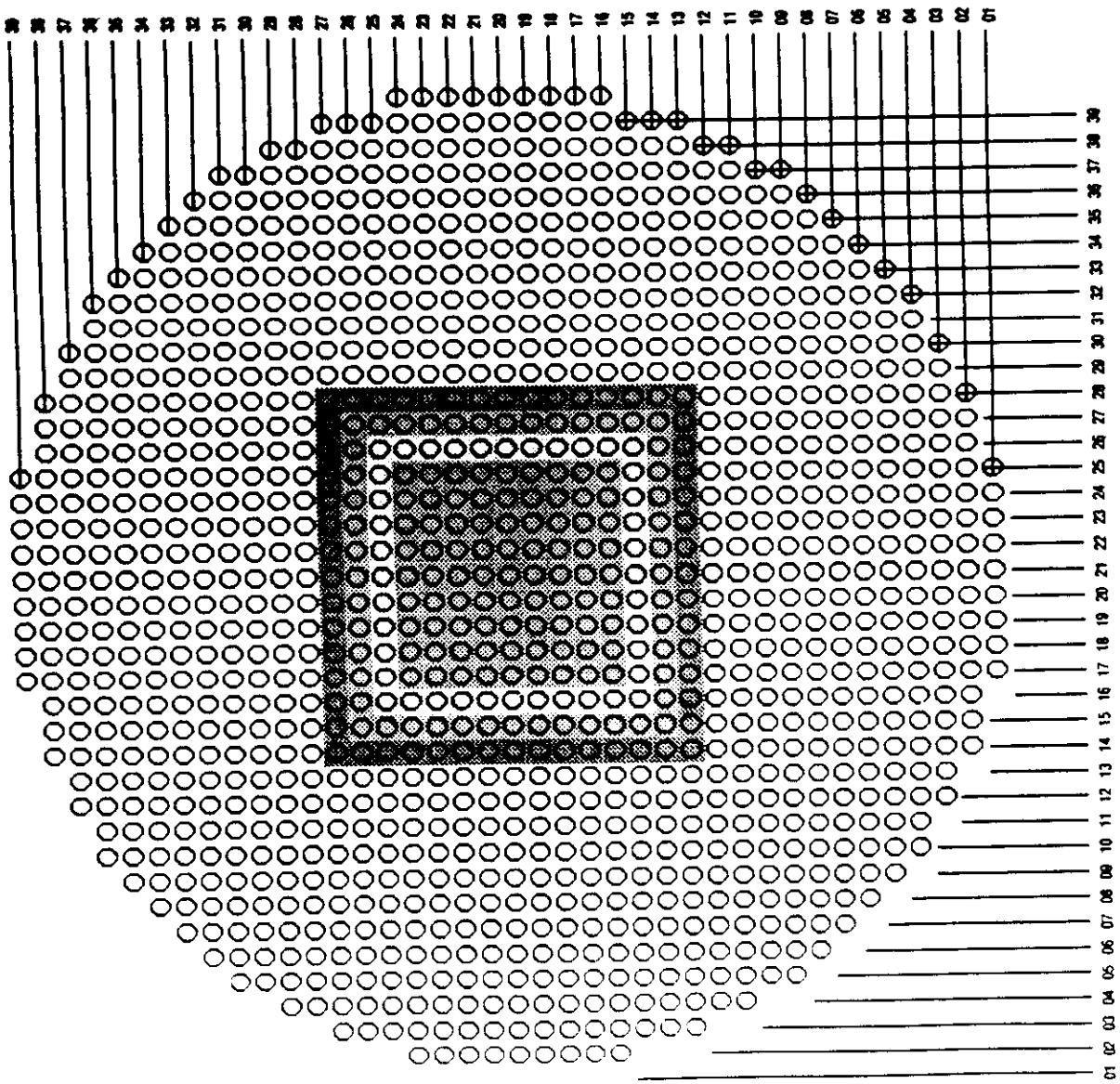


# Keff VERSUS MODERATION RATIO

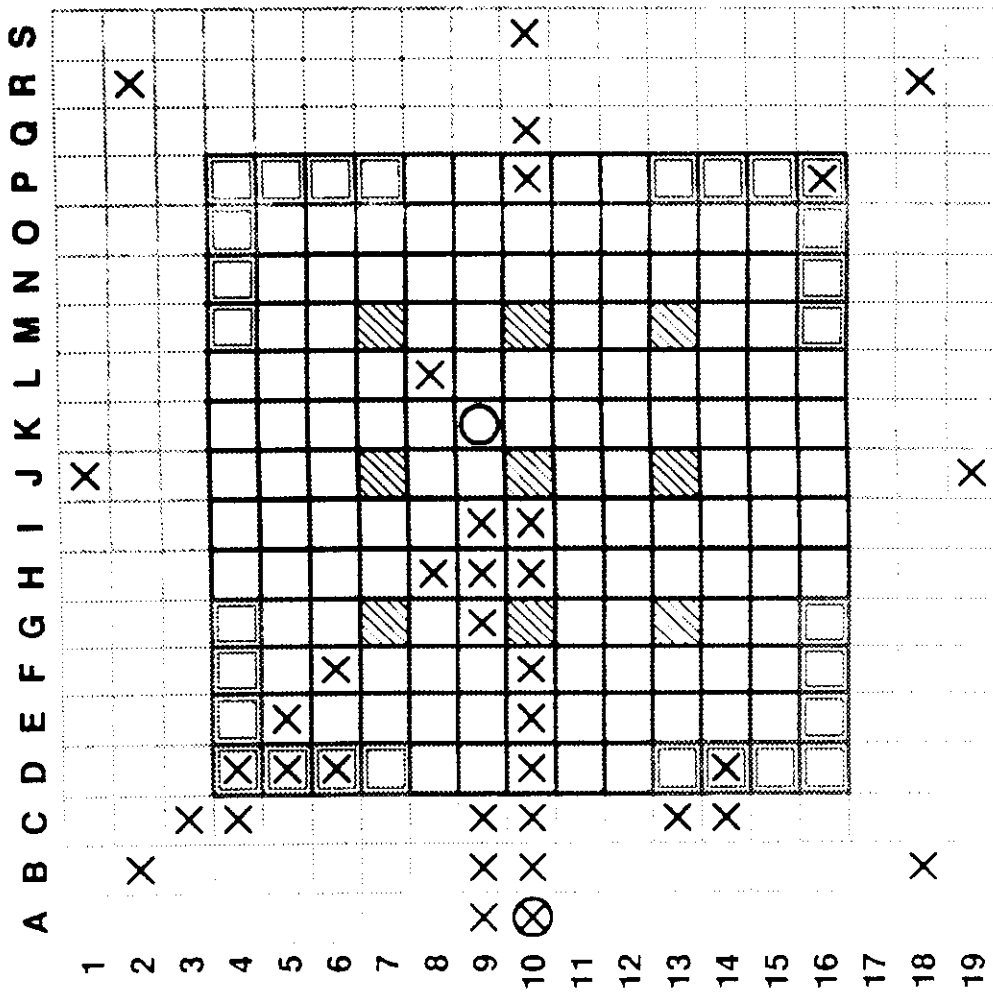


# BATTELLE EXPERIMENTS

- $\text{PuO}_2$  (4%)
  - $\text{UO}_2$
  - $\text{PuO}_2$  (0.9%)
  - $\text{PuO}_2$  (2%)
  - $\text{PuO}_2$  (2%)
- } 2 different  
PU 240 amounts

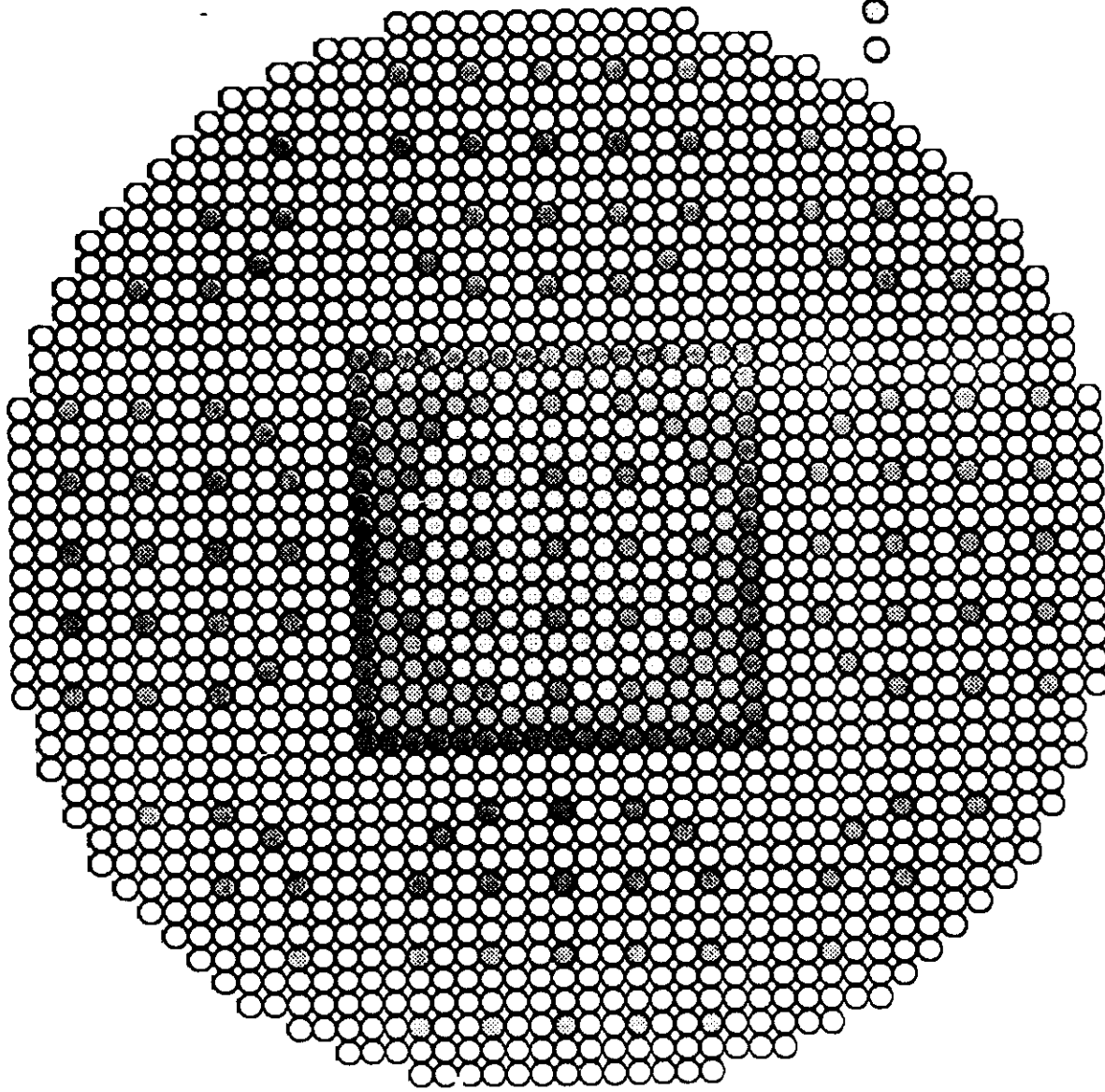


# MINERVE EXPERIMENT



$\text{UO}_2 - \text{PuO}_2$  (4%)  
  $\text{UO}_2 - \text{PuO}_2$  (3,6%)  
 Axial distribution measurement  
X Radial distribution measurement

# EPICURE



○ UO<sub>2</sub> FUEL RODS

○ ○ ○ CENTRAL MOX ASSEMBLY

4.3 % (64 pins)

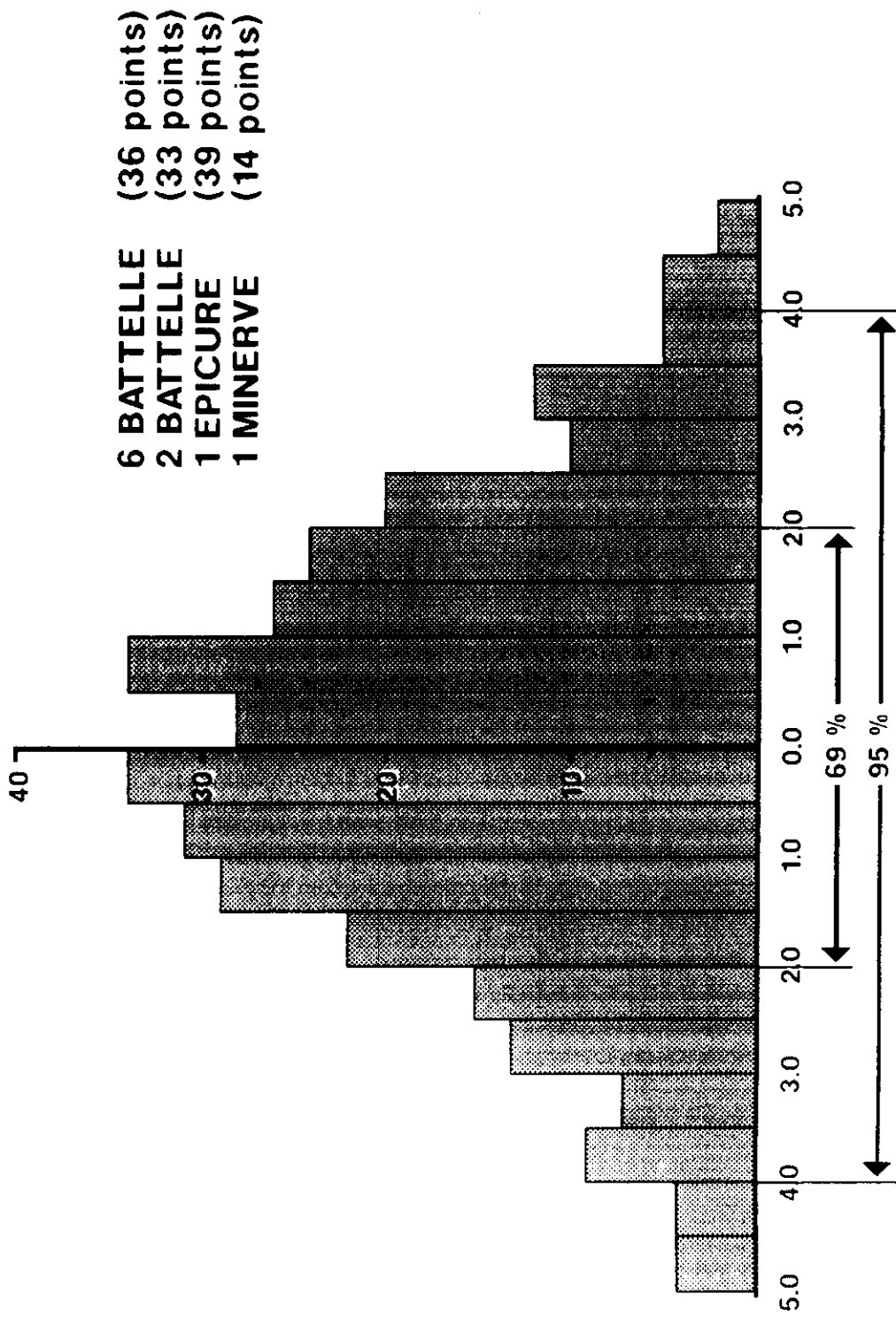
7.0 % (100 pins)

8.7 % (100 pins)

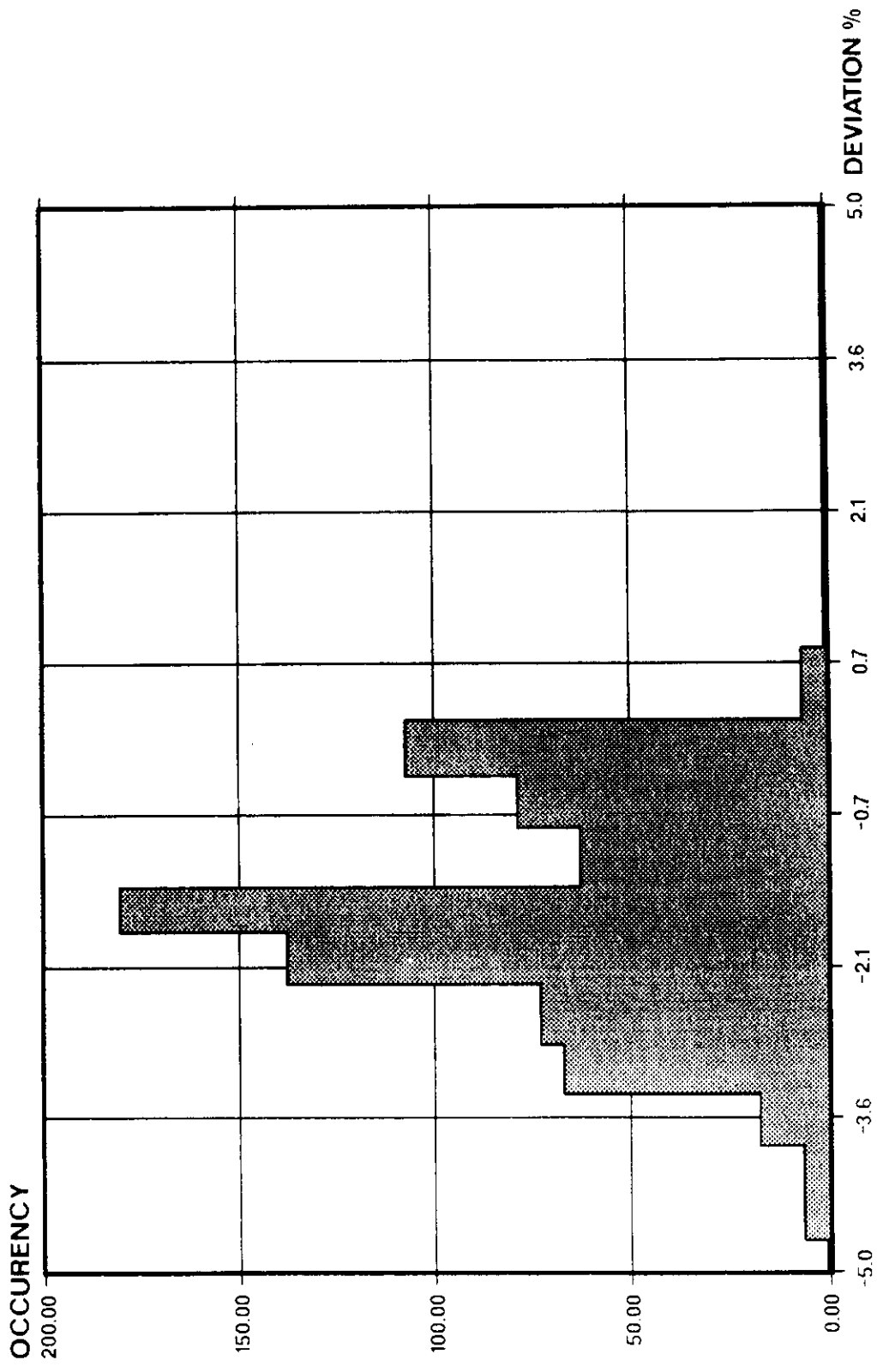
○ GUIDE-TUBES



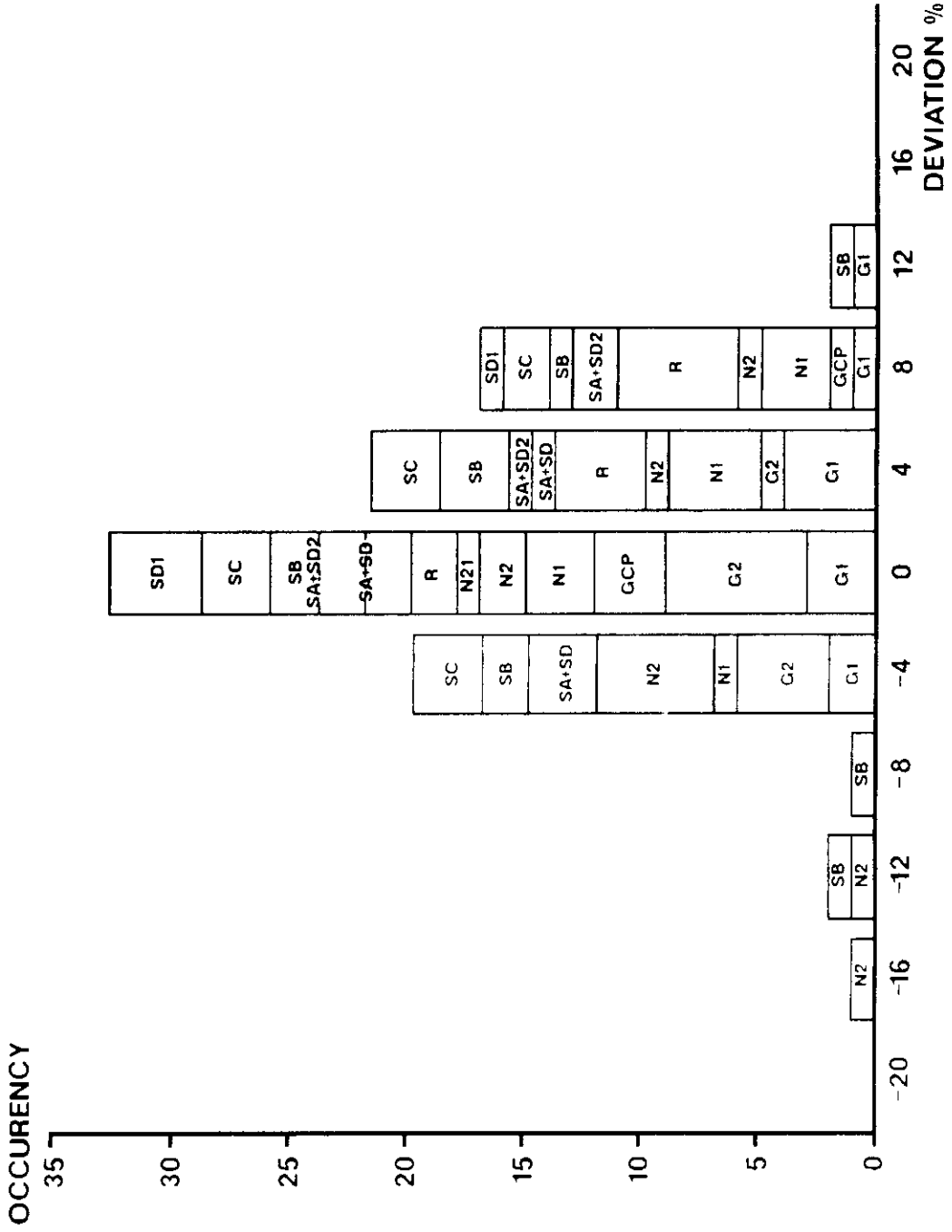
# OVERALL RESULTS HISTOGRAM



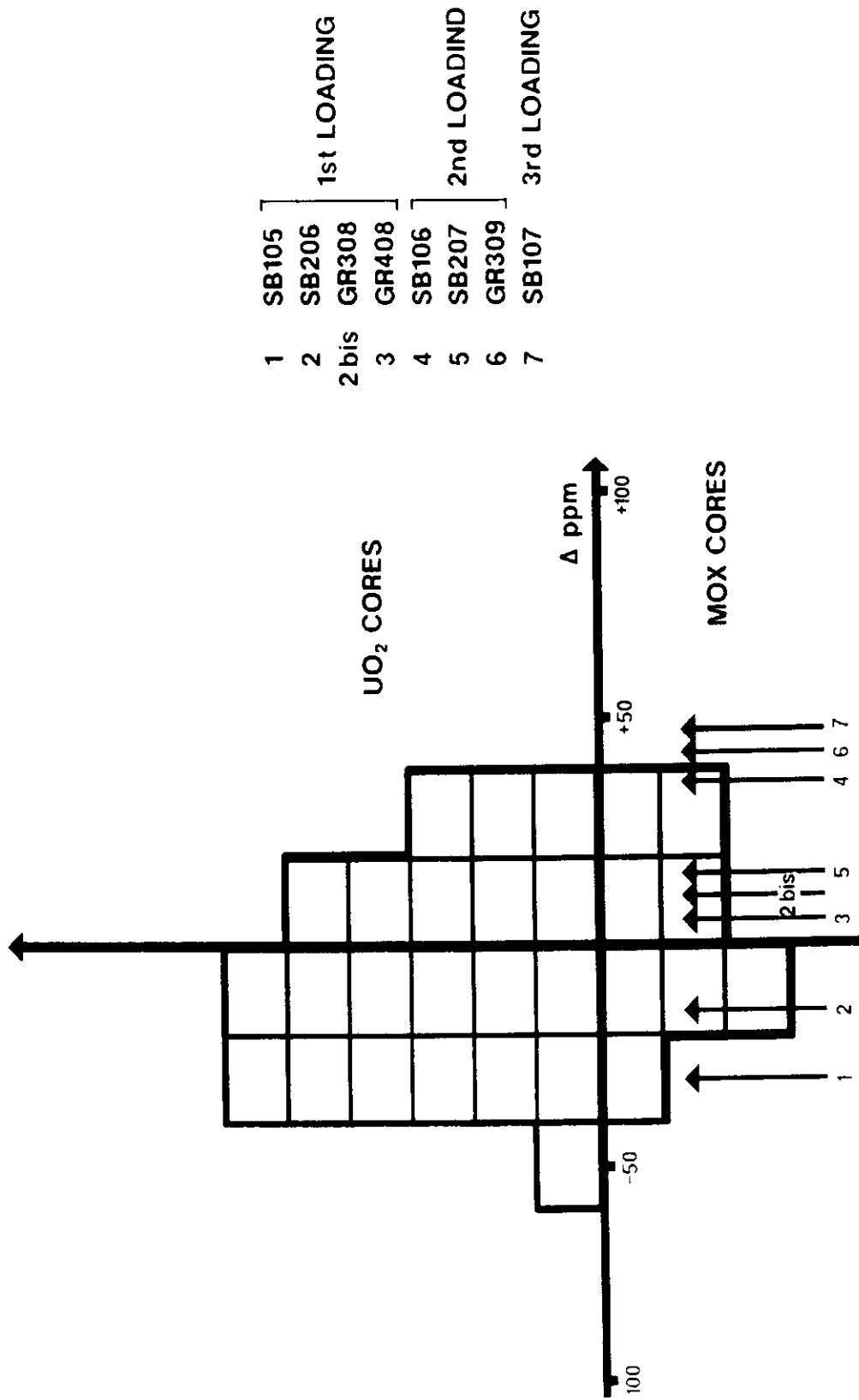
# MOX ASSEMBLY ACTIVITIES (751 VALUES)



# CONTROL ROD REACTIVITY WORTH



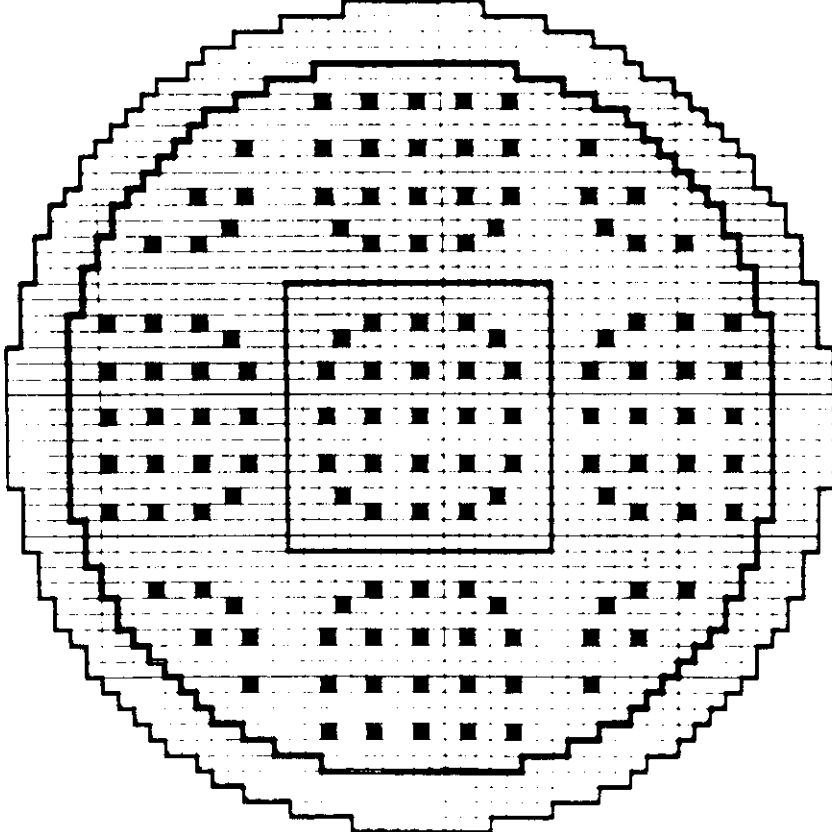
# BORON CONCENTRATION DEVIATION



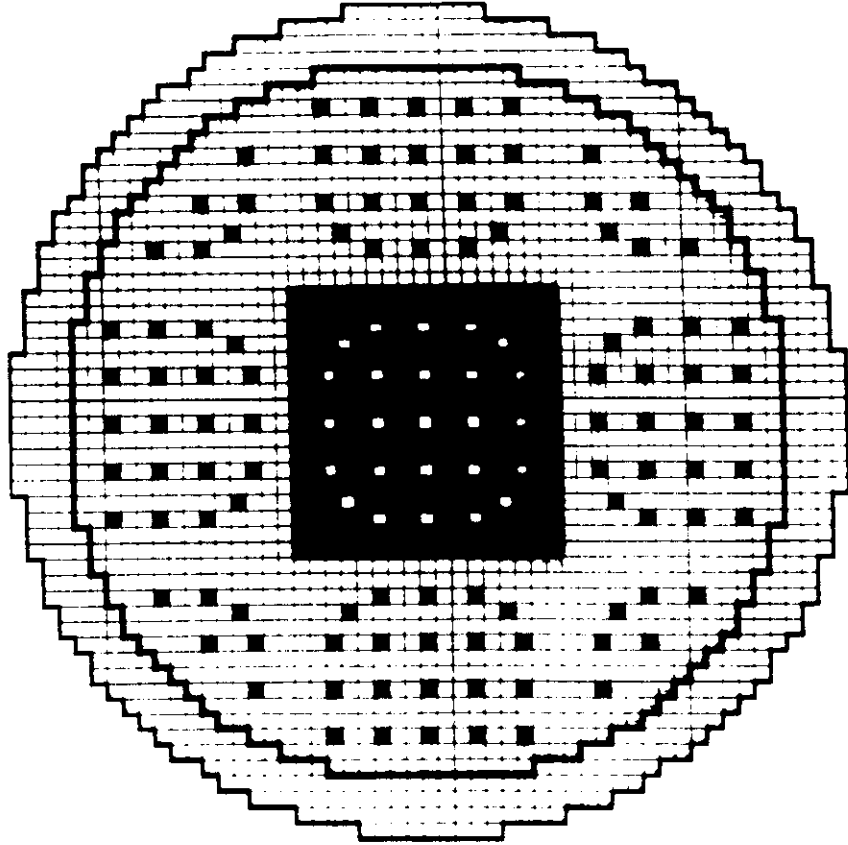
***POINT-WISE POWER DISTRIBUTION ANALYSIS:  
THE EPICURE EXPERIMENT***



**Standard UO<sub>2</sub> CORE CONFIGURATION**

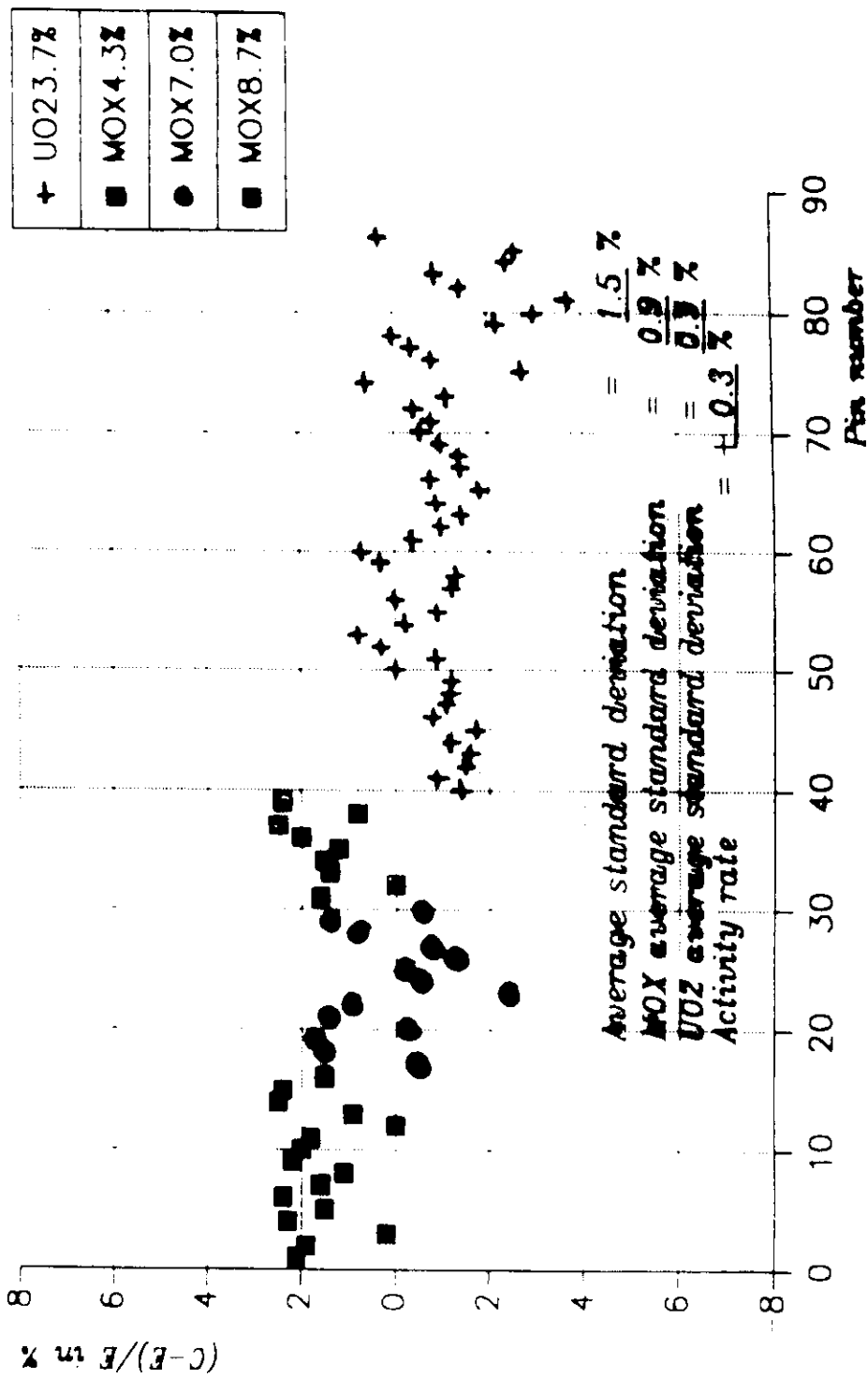


# The UM-ZONE Configuration





*Dispersion of discrepancies (C-E)/E in percent  
APOLLO II - Sn Transport - 99 Energy groups  
MEEK & RIDER Yields*





FRAMATOME

# Dispersion of discrepancies (C-E)/E in percent APOLLO II - Sn Transport - 99 Energy groups JEF 2.2.2 Yields

