106


KFKI Atomic Energy Research Institute

# THE SOLUTION OF THE LEU AND MOX VVER-1000 CALCULATION BENCHMARK WITH THE KARATE-MULTICELL CODE

G. Hordósy, Cs. Maráczy
KFKI Atomic Energy Research Institute
P.O.Box 49
Budapest, Hungary H-1525
Phone: +36 1 392-2222 ext. 14-99
Fax: +36 1 395-9293
E-mail: maraczy@sunserv.kfki.hu

## INTRODUCTION

- **Preparations for disposition of weapons grade plutonium in VVER-1000 reactors are in progress.**
- **Benchmark: Defined by the Kurchatov Institute (S.Bychkov, M.Kalugin, A.Lazarenko) to assess the applicability of computer codes for weapons grade MOX assembly calculations**
- **Framework : "Task Force on Reactor-Based Plutonium Disposition" of OECD Nuclear Energy Agency .**

## BENCHMARK PROBLEM

**Burnup calculation of two VVER-1000 assemblies:**

- **Uniformly enriched LEU fuel assembly with 12 U-Gd integrated burnable absorber rods**

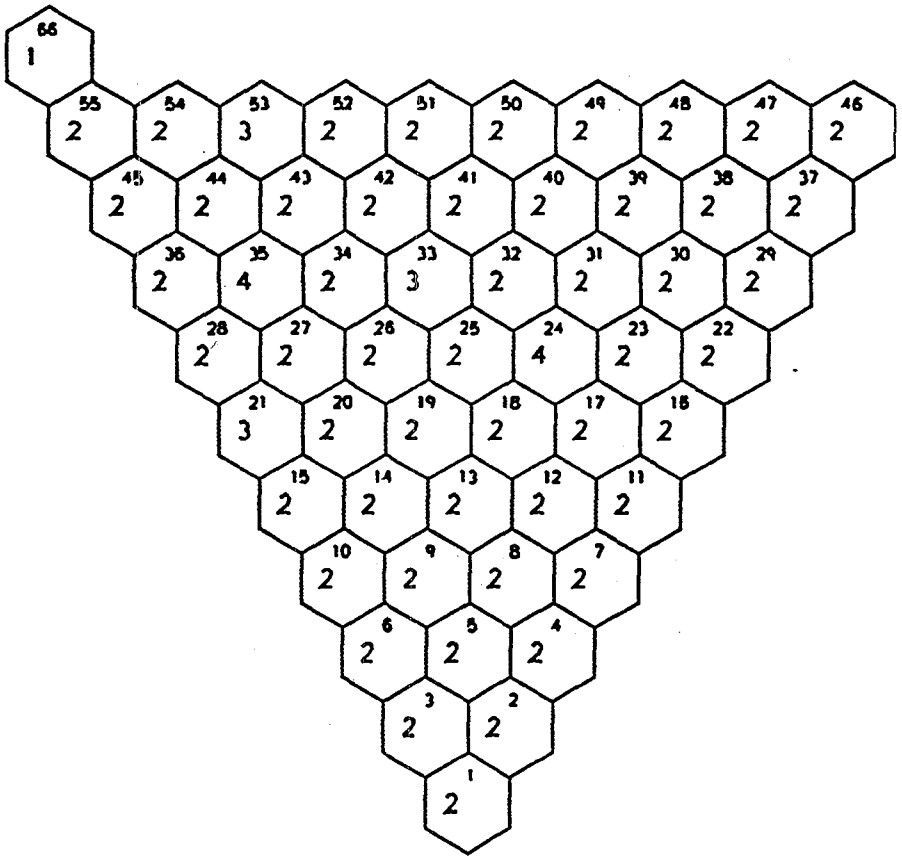
- **Profiled weapon grade MOX fuel assembly with 12 U-Gd integrated burnable absorber rods**

**States to be calculated:**

- **Burnup calculation at nominal parameters up to 40 [MWd/kgHM]**

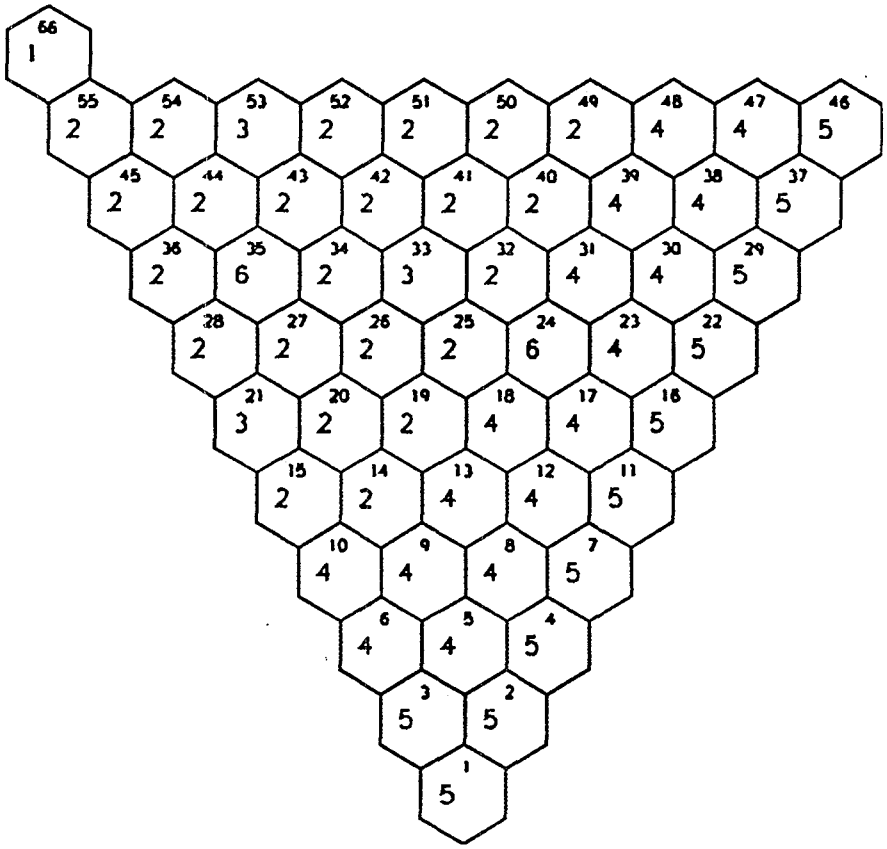
- **States at 0., 20. and 40 [MWd/kgHM]:**

| | |
|---|---|
| **S1** | **Operating poisoned state** |
| **S2** | **Operating non-poisoned state** |
| **S3** | **Hot state** |
| **S4** | **Hot state without boric acid** |
| **S5** | **Cold state** |




## LEU fuel assembly with 12 U-Gd rods

1 Instrumentation tube
2 $UO_2$ fuel pin (E=3.7 w/o)
3 Absorber guide
4 $UO_2$ fuel pin (E=3.6 w/o) with 4 w/o $Gd_2O_3$ absorber




## MOX fuel assembly with 12 U-Gd rods

1 Instrumentation tube
2 MOX fuel pin (E=4.2 w/o)
3 Absorber guide
4 MOX fuel pin (E=3.0 w/o)
5 MOX fuel pin (E=2.0 w/o)
6 $UO_2$ fuel pin (E=3.6 w/o) with 4 w/o $Gd_2O_3$ absorber

# THE KARATE-MULTICELL CODE

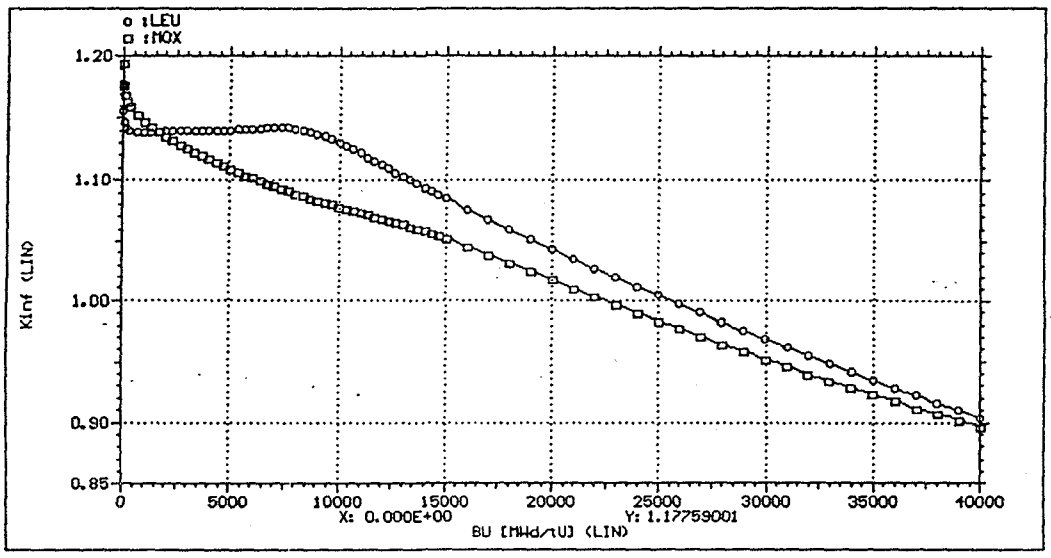
- KARATE code system: Calculation of neutron physical and therma hydraulic processes in the VVER-440 core
- Assembly transport calculations: MULTICELL code ( tested agains measurements on the ZR-6 critical assembly)
- Multigroup calculations: 35 epithermal and 35 thermal energy group ,thermal cut-off: 1.84eV.
- Nuclear data: based on ENDF/B-VI library, processed by NJOY anc PEACO
- Resonance isotopes: U-235, U-238, Pu-239 (equivalence theory) Pu 240 : Explicit treatment in the thermal region with Doppler broadening.
- Collision probabilities: Combination of cell transmission, escap probabilities and the collision probabilities inside the cylindrical cells Periodic boundary condition.
- Burnup calculations : 18 actinide and 145 fission product isotopes

# BENCHMARK CALCULATIONS

- $k_{inf}$ values , fission rate distributions, isotpic composition
- Cold state (S5) at zero burnup: MCNP Monte Carlo calculations , LEU and MOX

| State | MCNP $k_{inf}$ | MCNP $k_{inf}$ st.dev. | MULTICELL $k_{inf}$ |
|---|---|---|---|
| LEU S5 Bu=0 | 1.31759 | 0.00026 | 1.3164 |
| MOX S5 Bu=0 | 1.32073 | 0.00025 | 1.3249 |

$K_{inf}$ results for selected cases.




MULTICELL $k_{inf}$ vs. burnup
LEU and MOX operating poisoned states.

# REFERENCES

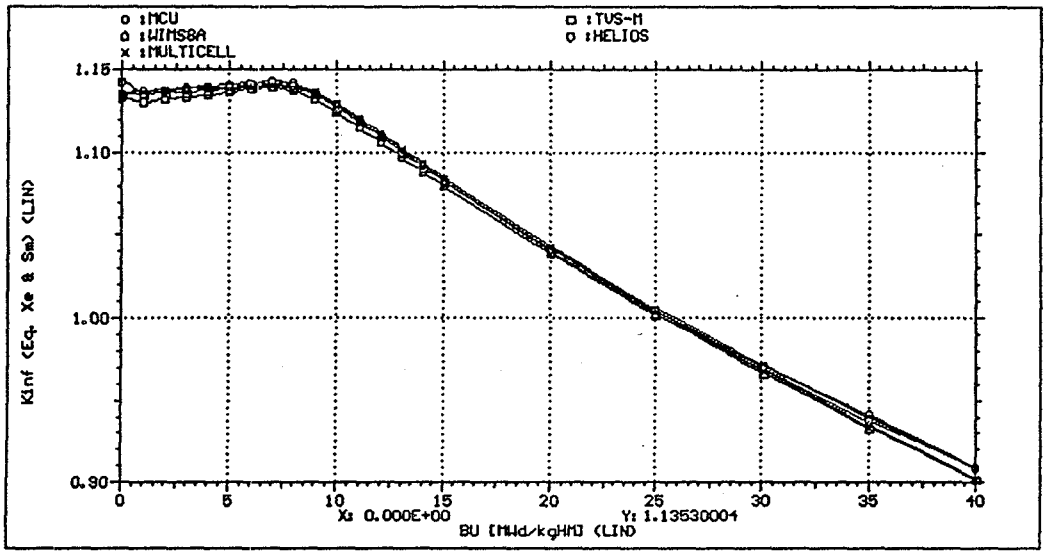
1. S.Bychkov, M.Kalugin, A.Lazarenko, "Proposal for LEU and MOX VVER Calculational Benchmarks", Russian Research Center "Kurchatov Institute"

2. Gadó et al., "KARATE - A Code for VVER-440 Core Calculation", Transactions of ANS Winter Meeting, Washington DC, November 13-17,1994, p. 485, Vol. 71.

3. Gy. Hegyi et al., "Benchmark on Integral Parameters and Pin-Wise Energy Distributions of Heterogeneous Lattices", Proc. of the third Symposium of AER, Piestany, Slovakia, 27 September - 1 October 1993, p. 241

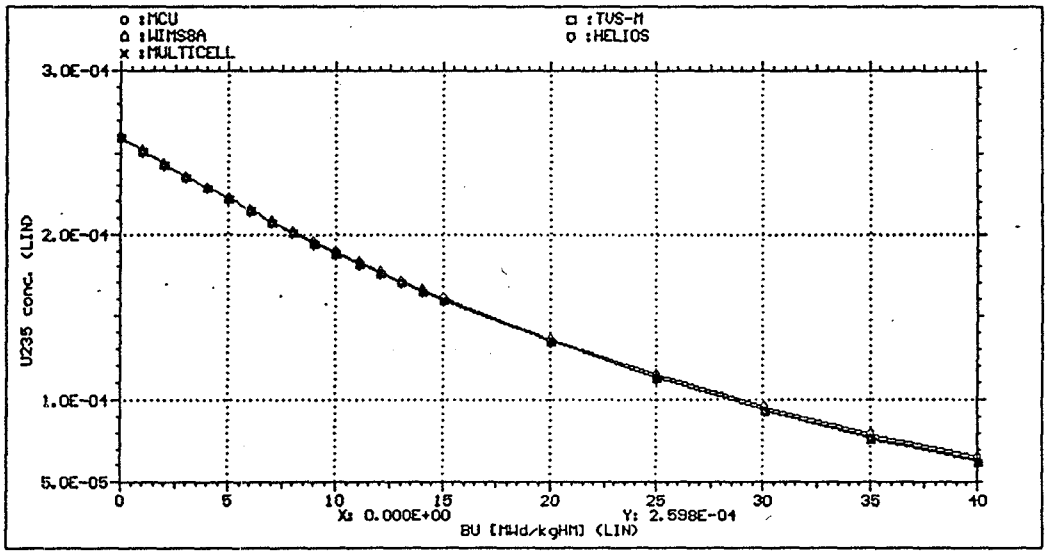
4. MacFarlane, D. W. Muir, The NJOY Nuclear Data Processing System, LA-12740-M, 1994

5. Y.Ishiguro, H. Takano, PEACO - A Code for Calculation of Group Constants of Resonance Energy Region in Heterogeneous Systems, JAERI 1219 report, 1971.



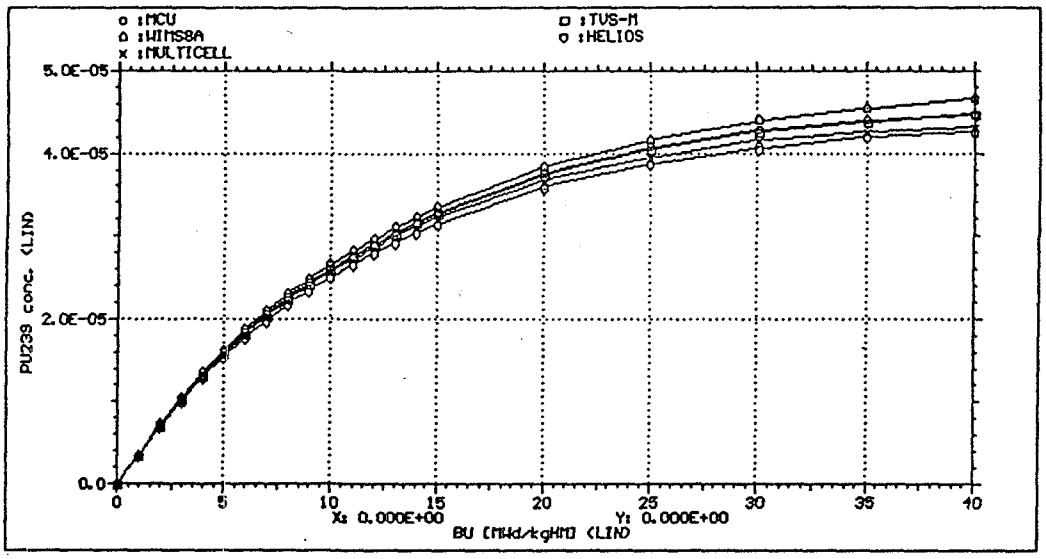

**LEU fuel assembly**

**$k_{inf}$ vs. burnup**



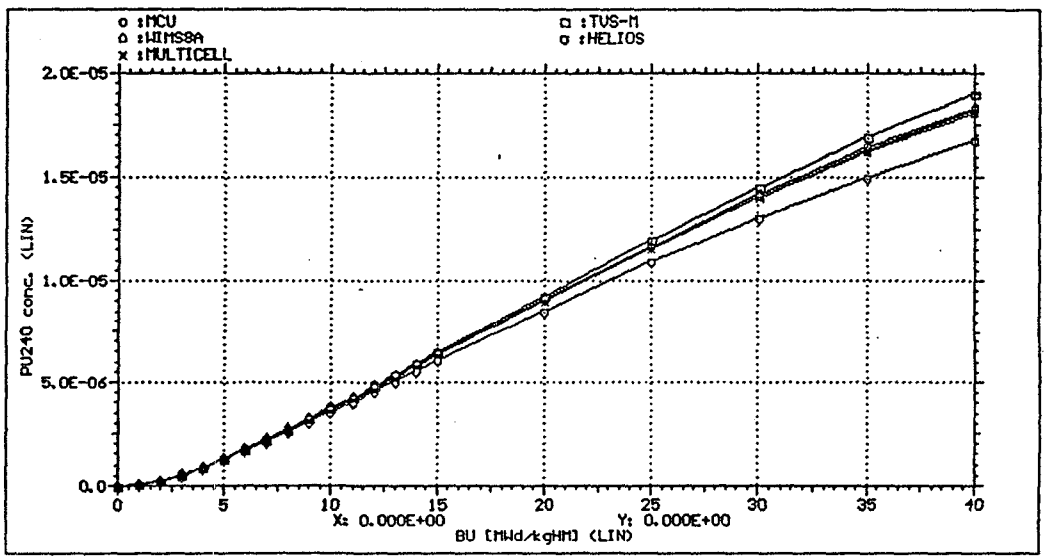

**LEU fuel assembly**

**Assembly averaged U-235 concentration vs. burnup**



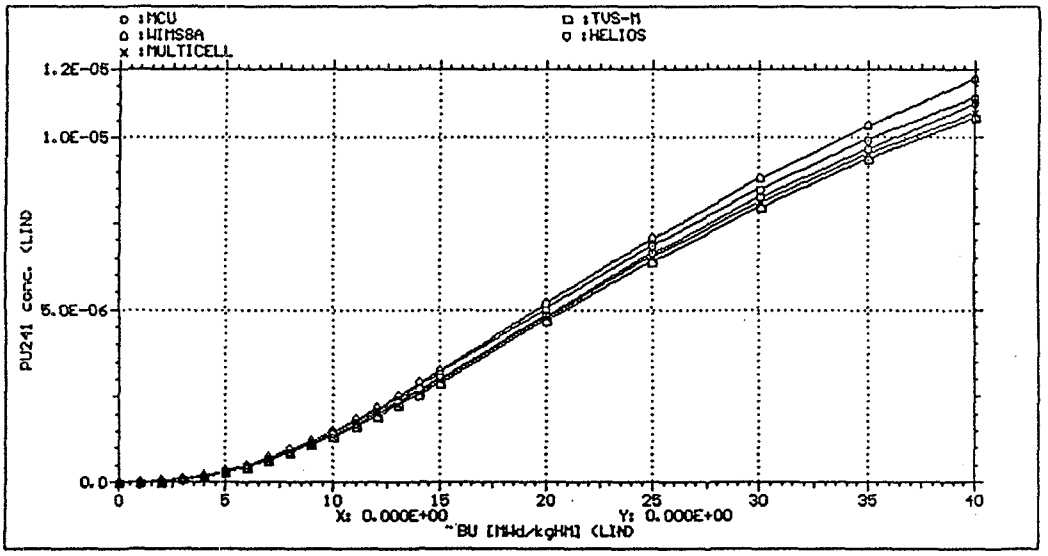

**LEU fuel assembly**

**Assembly averaged PU-239 concentration vs. burnup**




**LEU fuel assembly**

**Assembly averaged PU-240 concentration vs. burnup**

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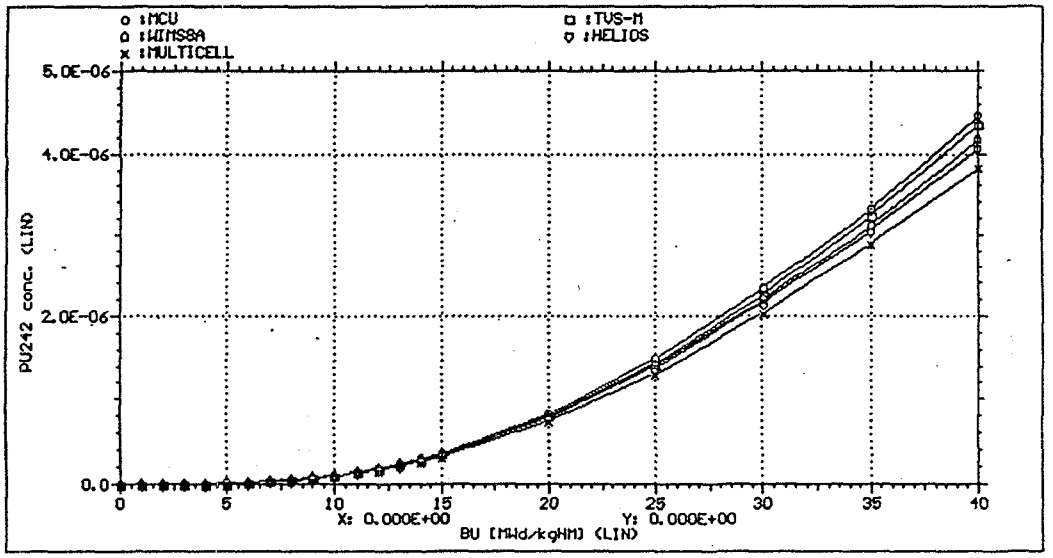


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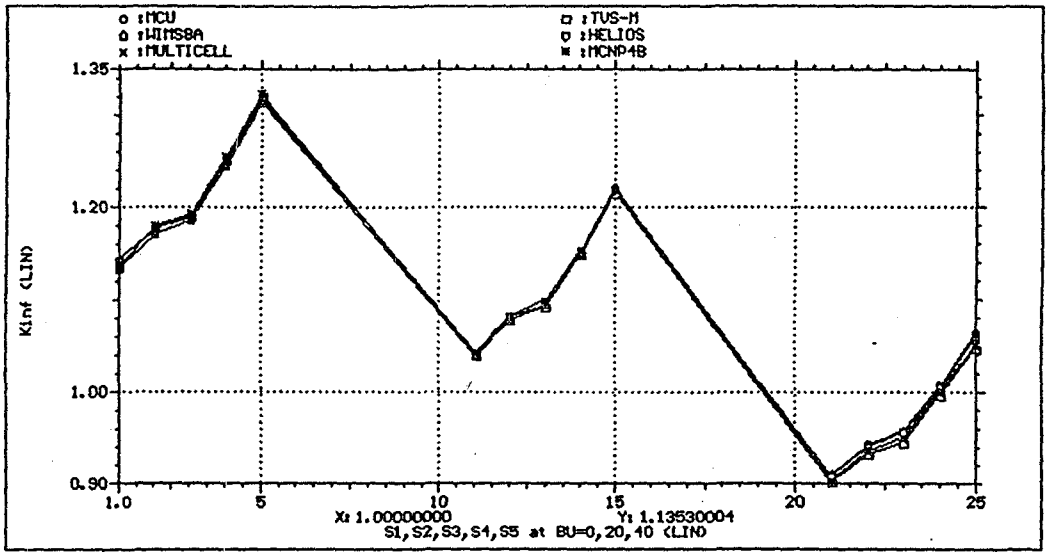
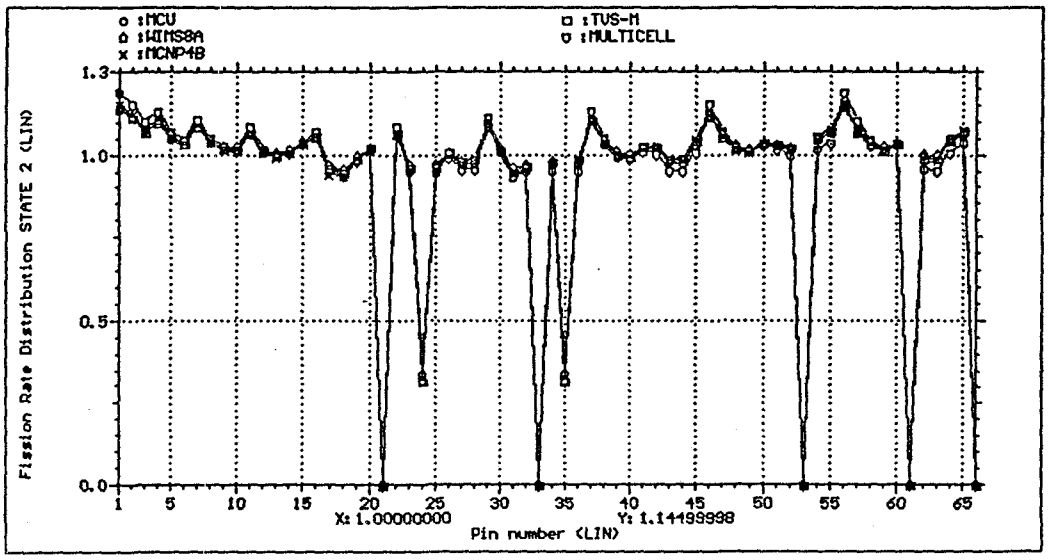


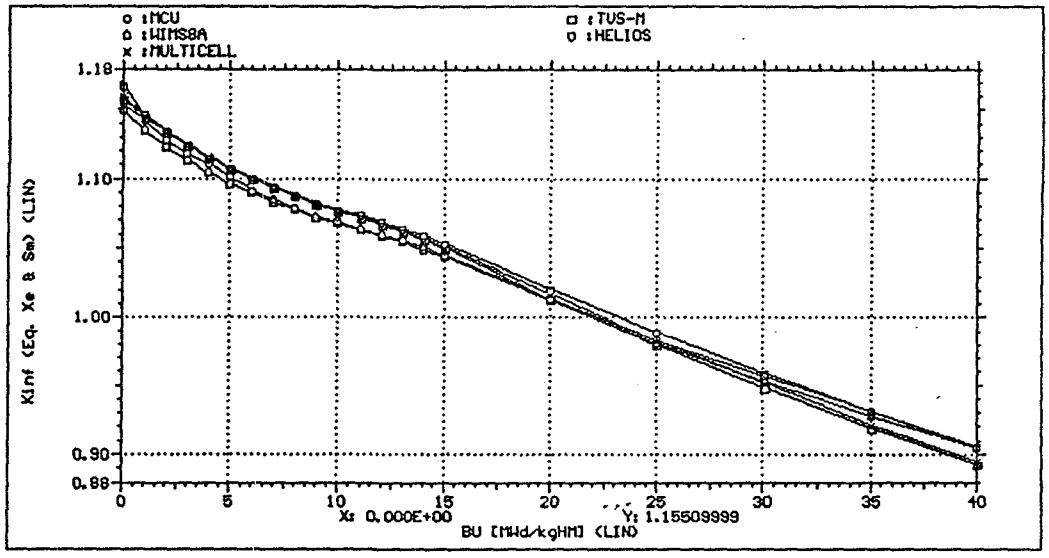

**LEU fuel assembly**

**$K_{inf}$ at burnup 0, 20, 40 [MWd/kgHM] for states S1-S5**



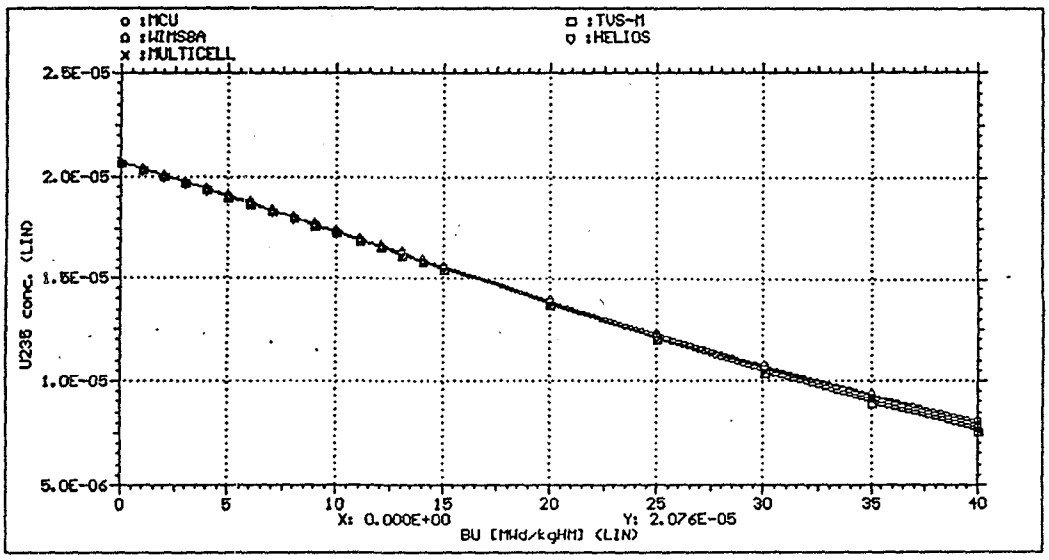

**LEU fuel assembly**

**Fission rate distribution vs. pin position number**



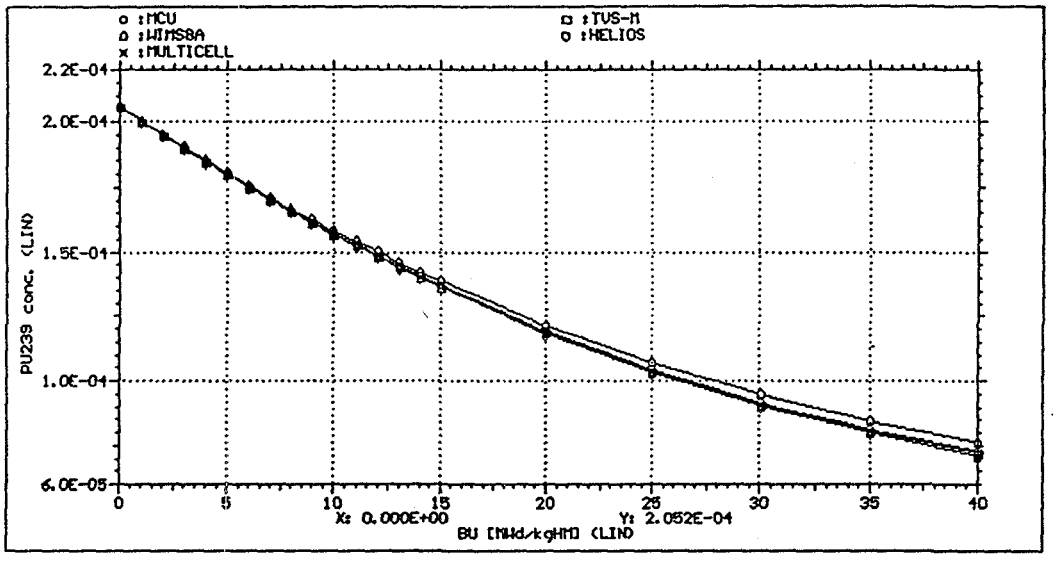

**MOX fuel assembly**

**$k_{inf}$ vs. burnup**

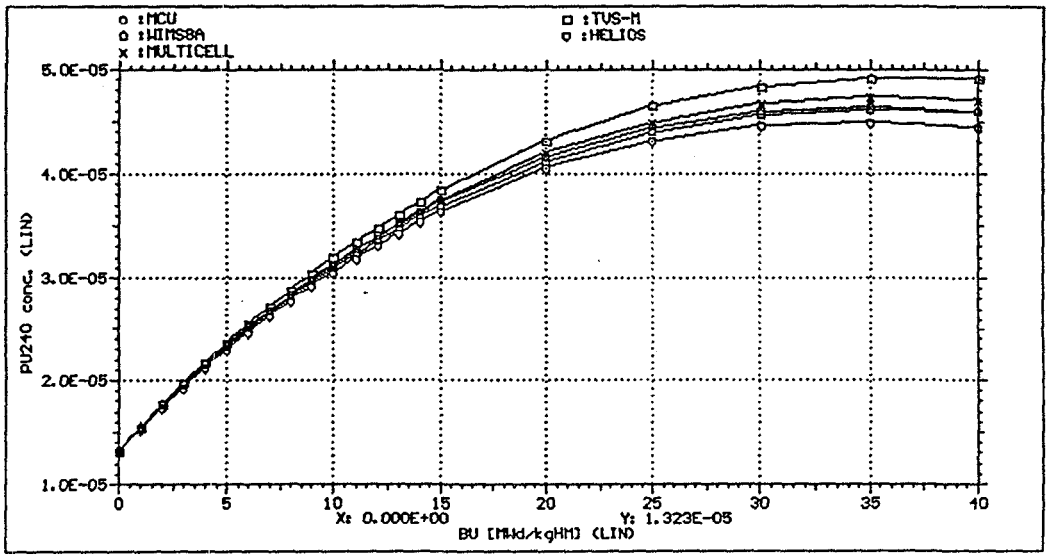



**MOX fuel assembly**

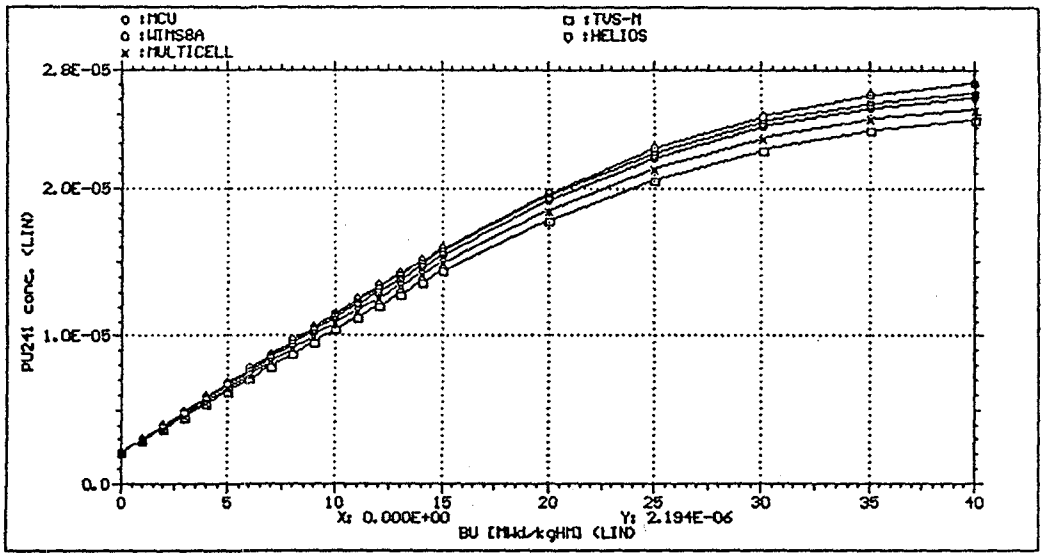
**Assembly averaged U-235 concentration vs. burnup**




**MOX fuel assembly**
**Assembly averaged PU-239 concentration vs. burnup**




**MOX fuel assembly**
**Assembly averaged PU-240 concentration vs. burnup**

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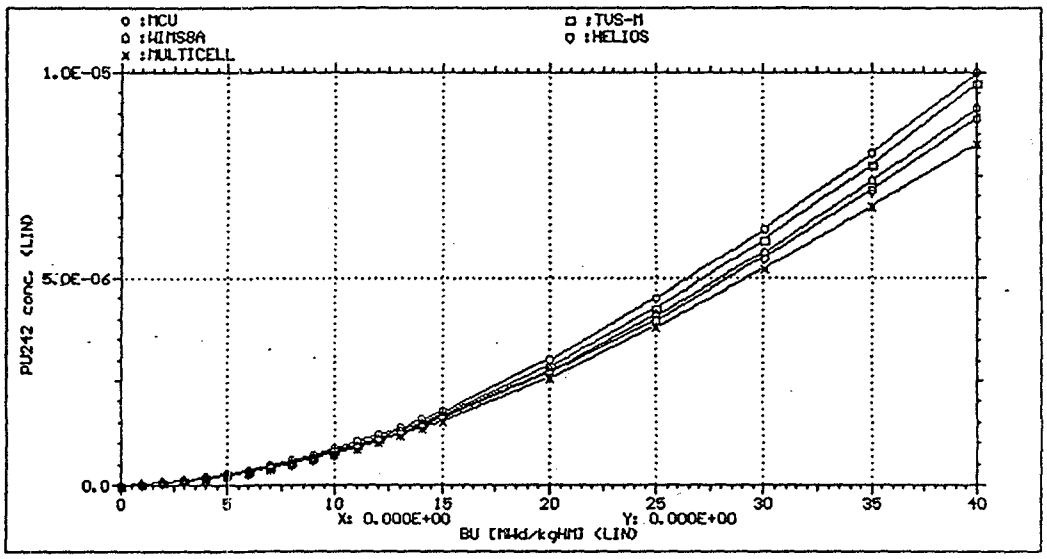
**Assembly averaged PU-241 concentration vs. burnup**

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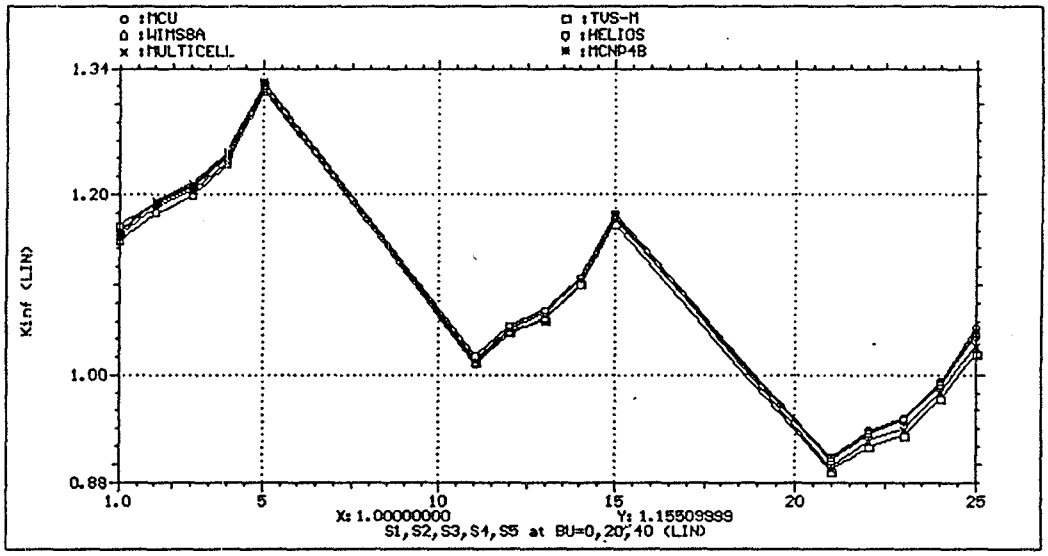


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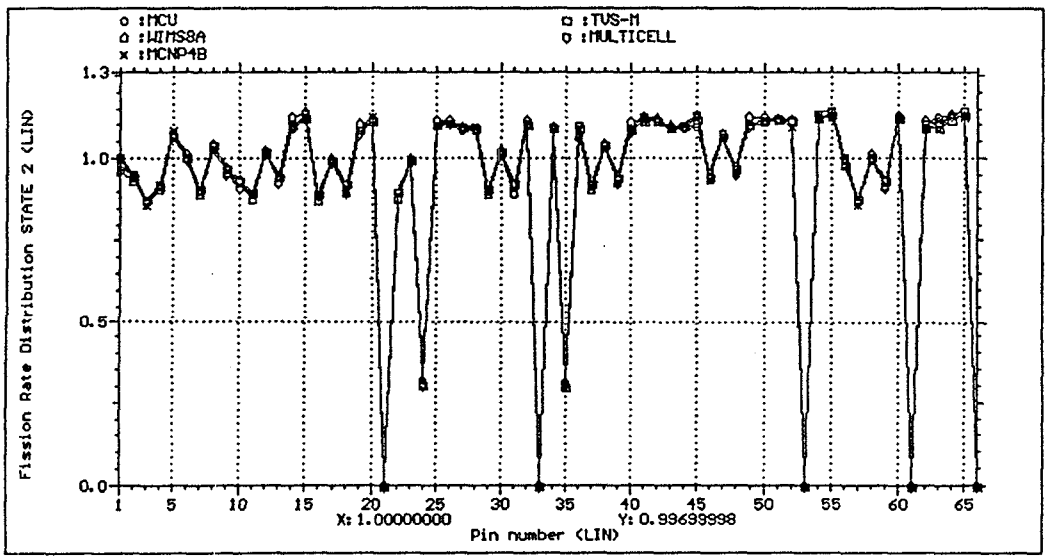


**MOX fuel assembly**

**Fission rate distribution vs. pin position number**