NEUTRONIC ANALYSIS FOR CONVERSION OF THE GHANA RESEARCH REACTOR-1 FACILITY USING MONTE CARLO METHODS AND UO_2 LEU FUEL

S. ANIM-SAMPONG

NATIONAL NUCLEAR RESEARCH INSTITUTE

GHANA ATOMIC ENERGY COMMISSION

PRESENTATION

- The GHANA RESEARCH REACTOR (GHARR-1) FACILITY
- CONSIDERATIONS FOR LEU CORES FOR GHARR-1 FUEL CYCLE ACTIVITIES AND OPERATIONS
- NEUTRONIC ANALYSIS OF GHARR-1 CORE USING HEU AND LEU (UO_2) FUELS
- RESULTS AND DISCUSSIONS
- CONCLUSION
- ACKNOWLEDGEMENT

The GHARR-1 FACILITY

- GHARR-1 facility is a tank-in-pool type LPRR
- Commercial version of Miniature Neutron Source Reactor (MNSR)
- GHANA MNSR facility acquired with IAEA Technical/HR Assistance (Reactors/Facilities under IAEA Project and Supply Agreement) via TC Project GHA/1/010
- Contract for GHANA MNSR signed in 12/1991

- GOV'T OF GHANA (GAEC)

- CHINA NUCLEAR INDUSTRY CORP.

- IAEA (3RD PARTY) AS WITNESS

The GHARR-1 FACILITY

- Facility is owned by Ghana Atomic Energy Commission, operated by National Nuclear Research Institute and regulated by Radiation protection Board (regulated body)
- Installed in Oct-Dec, 1994
- COMMISSIONED: MARCH 8, 1995

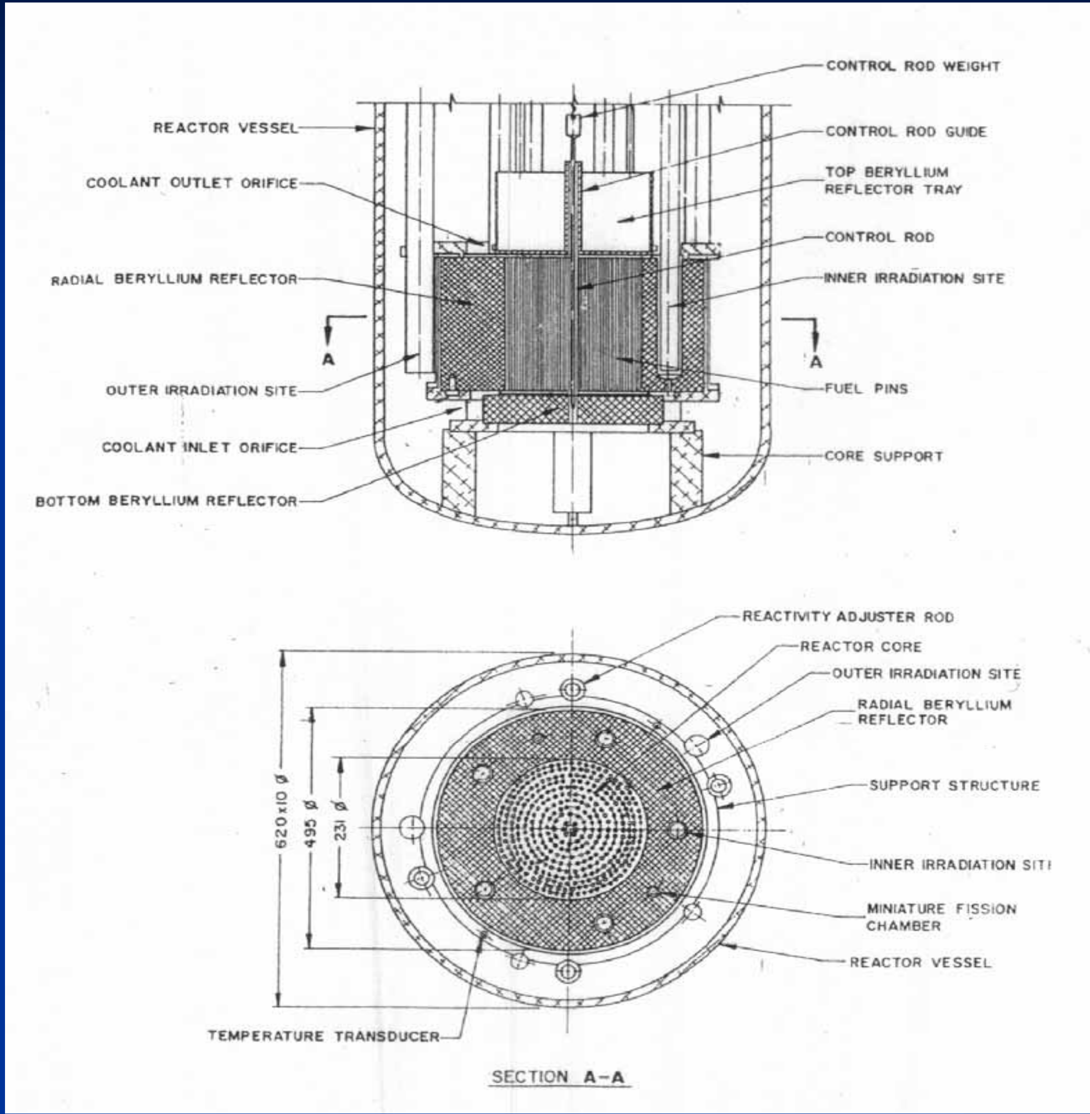
THE GHARR-1 FACILITY

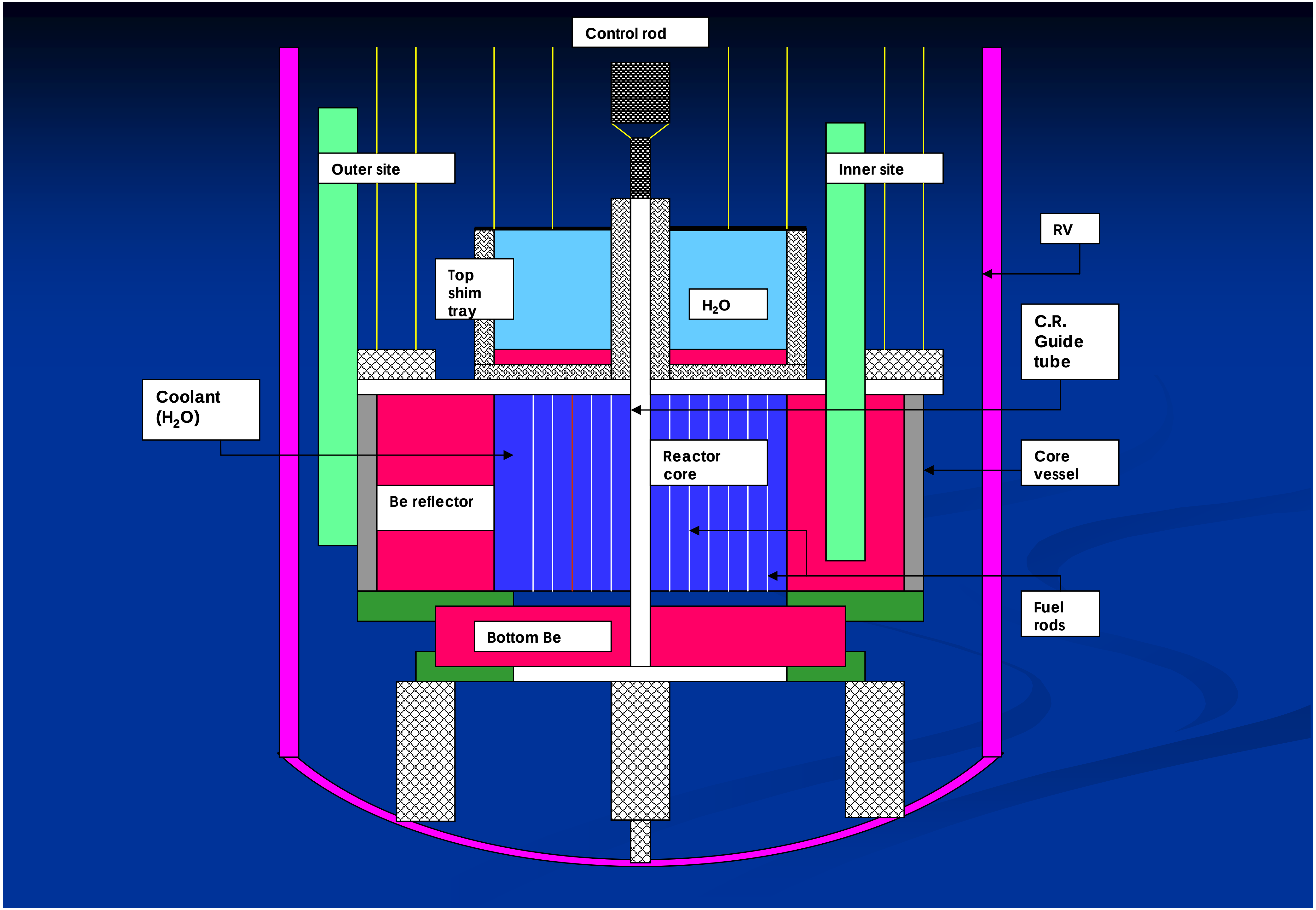
THE GHARR-1 FACILITY

The GHANA RESEARCH REACTOR -1 (GHARR-1) FACILITY: TECH SPECS

- Core power 30kW
- Cold excess reactivity ≤ 4mk
- Worth of control rod ~ 6.8-7mk
- Initial shutdown margin ≥ 3mk
- Thermal neutron flux
  - In-core ave. @ 30 kW $1.0E+12 n/cm^2.s$
  - Inner irrad. channel $1.0E+12 n/cm^2.s$
  - Outer irrad. channel $5.0E+11 n/cm^2.s$
- Mod. reactivity coeff. $-0.092 mk/^0C$

XS VIEW OF GHARR-1 & CORE CONFIGURATION




Control rod
Outer site
Inner site
RV
Top shim tray
H_2O
C.R. Guide tube
Coolant (H_2O)
Reactor core
Core vessel
Be reflector
Fuel rods
Bottom Be

GHARR-1 PHYSICS DESIGN AND SAFETY

- Under-moderated with an H/U atom ratio of 197, contributing to a high negative temperature coefficient (-0.1mk/oC) to boost its inherent safety properties.
- Additionally, the excess reactivity of the reactor is limited to $\rho_{ex} \leq ½\, \beta_{eff}$.
- This ensures that prompt criticality is not possible. Because of the safety provided by the combination of the reactor's limited excess reactivity (4mk under normal conditions) and its self-limiting power excursion response (due to its negative temperature coefficient)

GHARR-1 PHYSICS DESIGN AND SAFETY

- Core cooling is achieved by natural convection using light water.
- Heavy reflection on the side and underneath the fuel cage with thick annulus and slab of beryllium alloy material respectively, to minimize neutron loses and conserve neutron economy.

CONSIDERATIONS FOR LEU MNSR CORES

- Core replacement after excess reactivity drop to 2.5-2.8mk, all Be shims used up!
- Replacement options: HEU or LEU
- Consideration Factors:

- International trend in HEU-LEU conversions
- International Politics
- Fuel cycle [front end (supply) & back end (take-back)]
- etc

CONSIDERATIONS FOR LEU MNSR CORES

- Fuel Cycle – Key index for continued cycle operations of GHARR-1 facility

- Establish HEU – LEU R&D activities to address fuel cycle/associated activities in 1996 @ Nuclear Engineering & Materials Science Dept of National Nuclear Research Institute/GAEC

- HEU-LEU R&D analysis includes neutronic and thermal hydraulics analysis of reference HEU and suitable "candidate" LEU cores

Neutronic Analysis: 3-D Monte Carlo Model Method of Analysis

- MCNP4c3 and MCNP5 particle transport codes employed for Monte Carlo model of Ghana MNSR
- GHARR-1 Monte Carlo model is firmly established and can be adapted to any MNSR facility with little in tech specs, etc.
- Neutronically, the GHARR-1 Monte Carlo model provides for the simulation of reactor physics parameters such as nuclear criticality and core reactivities, neutron flux distribution in some selected locations of the reactor.

Neutronic Analysis: 3-D Monte Carlo Model & Method of Analysis

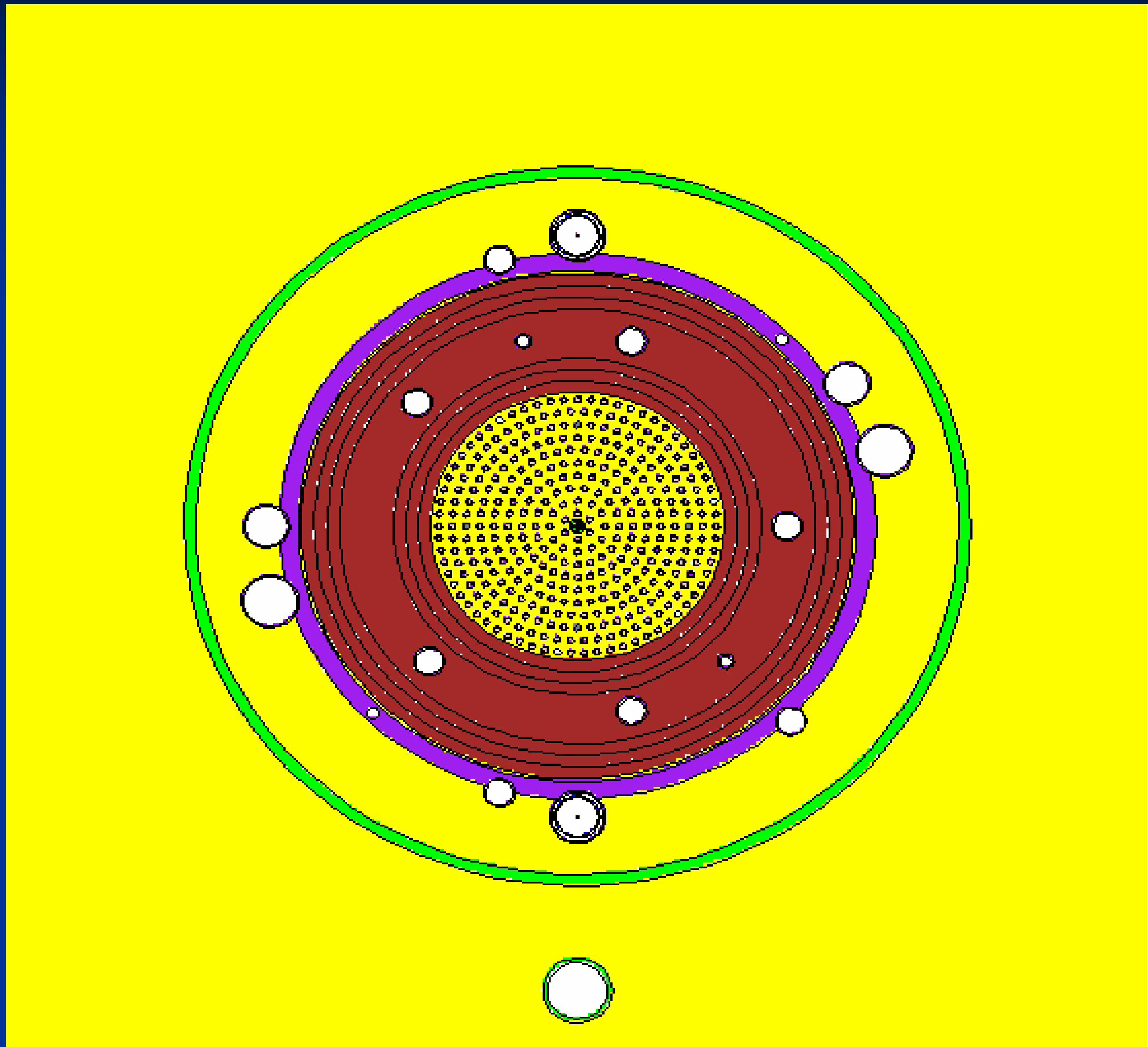
- Neutron transport simulations were done for clean fresh cores (zero burnup).
- Nuclear criticality calculations were performed to determine *keff* and corresponding core excess reactivities.
- For better statistics in this present analysis, the criticality specifications in the MCNP model provided for 400 kcode cycles and 500,000 source particles giving a total of 200 million neutron particle source histories.

Neutronic Analysis: 3-D Monte Carlo Model & Method of Analysis

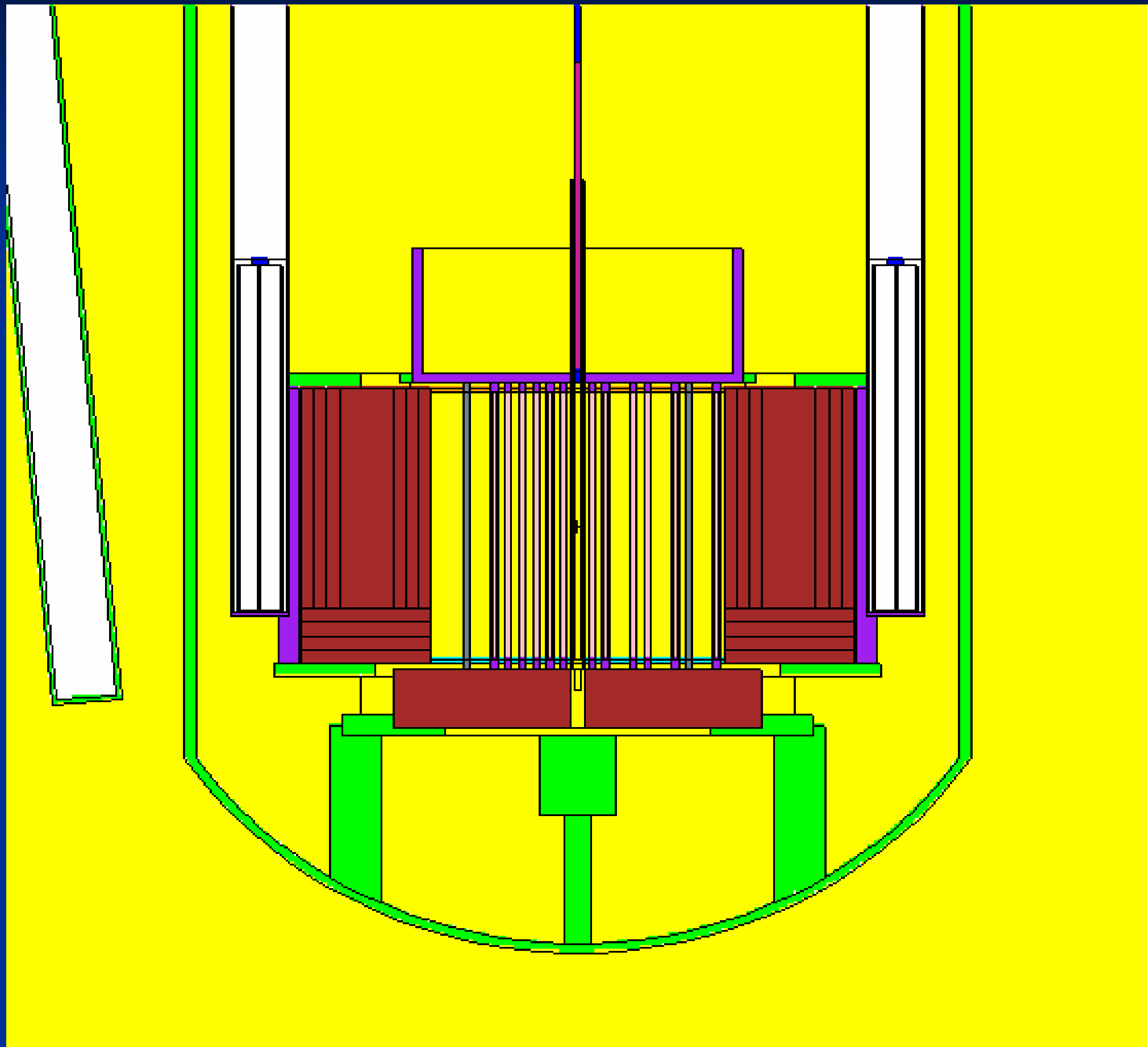
- A 3-group neutron energy structure condensed from an initial 7-subgroup structure of the Hansen-Roach continuous neutron energy group was used in the neutronic analysis.

- The special *S(αβ)* scattering feature of the MCNP code was applied in the nuclear model to treat thermal scattering in beryllium and hydrogen in light water for the reflector material and water regions respectively of the Monte Carlo model.

MCNP plot of GHARR-1 core configuration



MCNP plot of XS view of GHARR-1



NUCLEAR FUEL & CORECONFIGURATION

- HEU FUEL: 90.2%, 344 FE 6 dummy rods, 4 tie rods

- LEU FUEL: Three UO_2 types, varying enrichments

1. 12.6% enrichment , same configuration as reference HEU core

2. 19.75% (theoretical) enrichment: 238 FE, 112 Al dummies, 4 tie rods

3. 19.75% (theoretical) enrichment: 201 FE, 149 water dummies, 4 tie rods

Results and Discussions: criticality Safety

Fuel type	Criticality parameters and reactor status				
	Control rod withdrawn		Control rod inserted (reactivities in mk)		
	k_{eff}	ρ_{ex}	k_{eff}	Rod worth	SD margin
HEU	1.00454	4.5195	0.99701	-7.5526	-3.0331
LEU UO_2 (12.6%)	1.00454	4.5195	0.99797	-6.5834	-2.0624
LEU UO_2 (19.75%), Al	1.00481	4.7870	0.99862	-6.1985	-1.4115
LEU UO_2 (19.75%) W	1.00434	4.3213	0.99785	-6.5040	-2.1827

Results and Discussions: Criticality Safety

- In accordance with requirements for reactivity control and limiting conditions (OLC) for safe operation of the Ghana MNSR facility, the minimum and maximum reactivity worths of the cadmium control rod clad with stainless steel shall be 5.5mk and 7mk respectively
- Thus, for a fresh core with excess reactivity of 4mk, the corresponding minimum and maximum shutdown margins shall therefore be -1.5mk and -3mk respectively.

Results and Discussions: Criticality Safety

- From the results of the Monte Carlo criticality safety simulations, all three UO_2 LEU cores satisfy these conditions and thus qualify on this basis as suitable candidate LEU fuels for conversion of the HEU-fuelled GHARR-1 facility and hence any other MNSR cores.

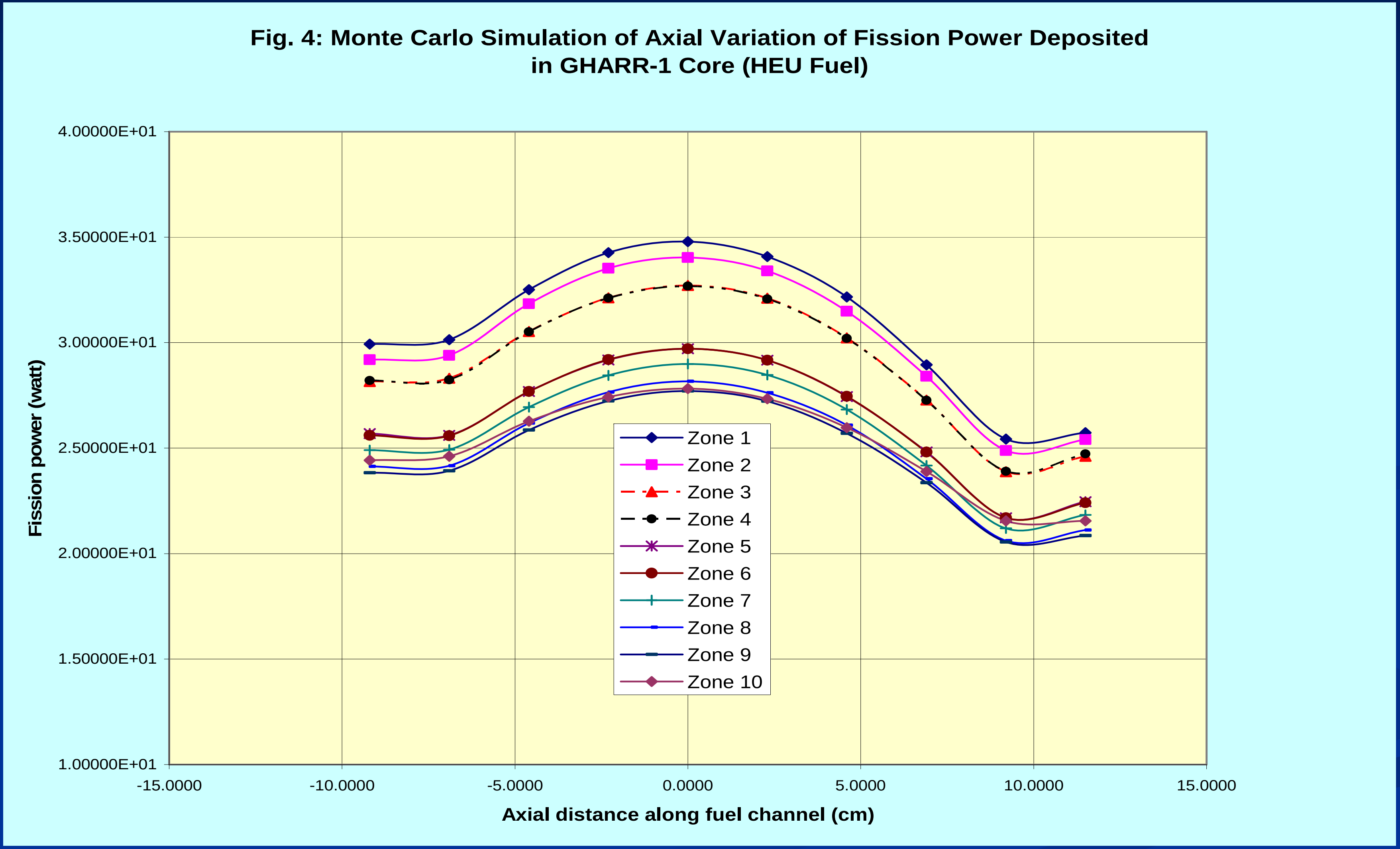
Results and Discussions: Power Distribution

- Monte Carlo simulation of the fission energy deposition on each fuel element and lattice zone provides for the establishment of the reactor power distribution across the GHARR-1 core for both HEU and LEU fuel assemblies.
- Fission power and fluxes peak at the centre of the fuel channels which was selected as the geometrical centre of the core

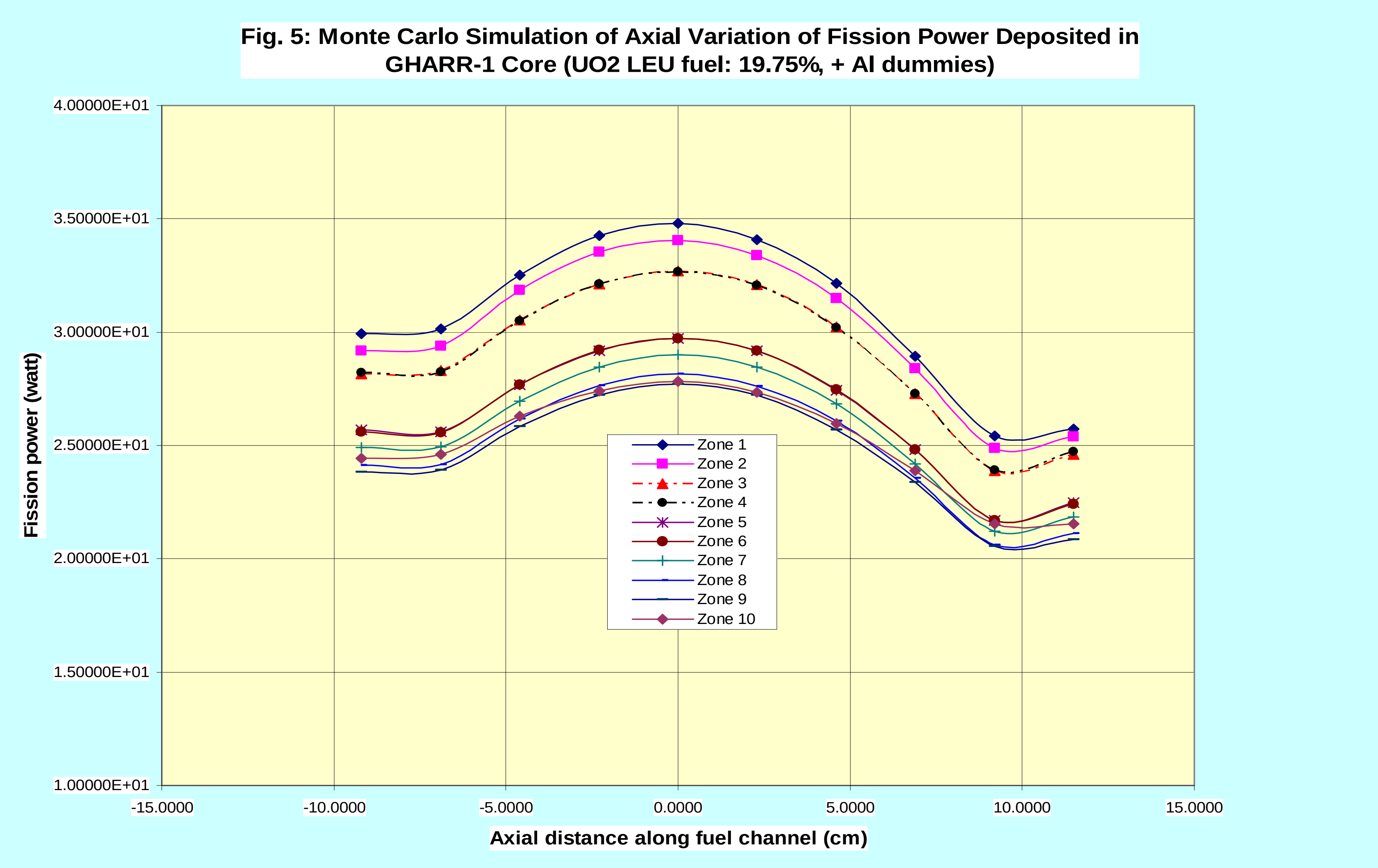
Results and Discussions: Power Distribution

- The same trend was observed for the UO_2 cores with different configurations and enrichment considered in this work.
- In general, for a given axial location, the fission power and fluxes were observed to be higher as the number of fuel elements in the fuel lattice zones increased.

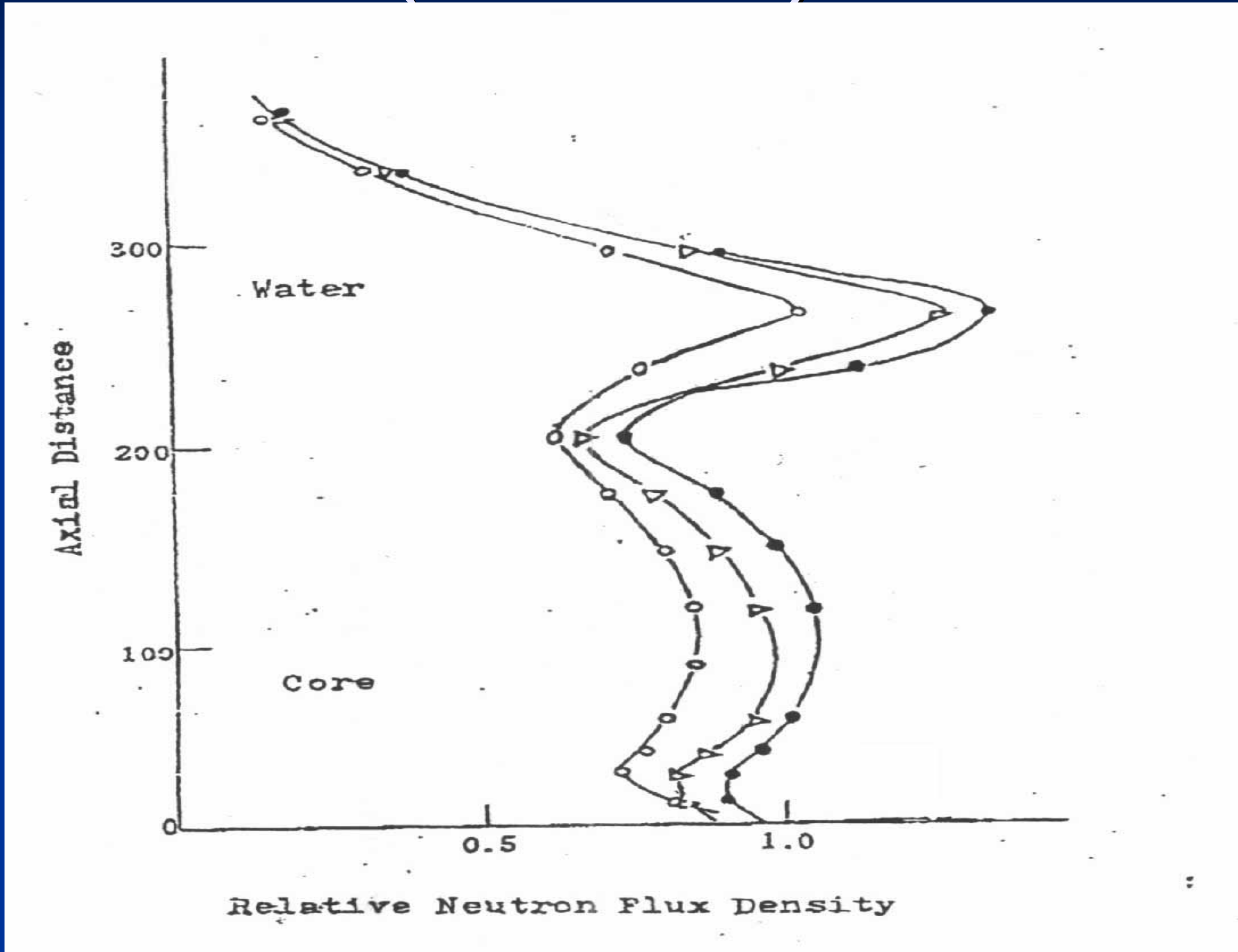
Results and Discussions: Power Distribution



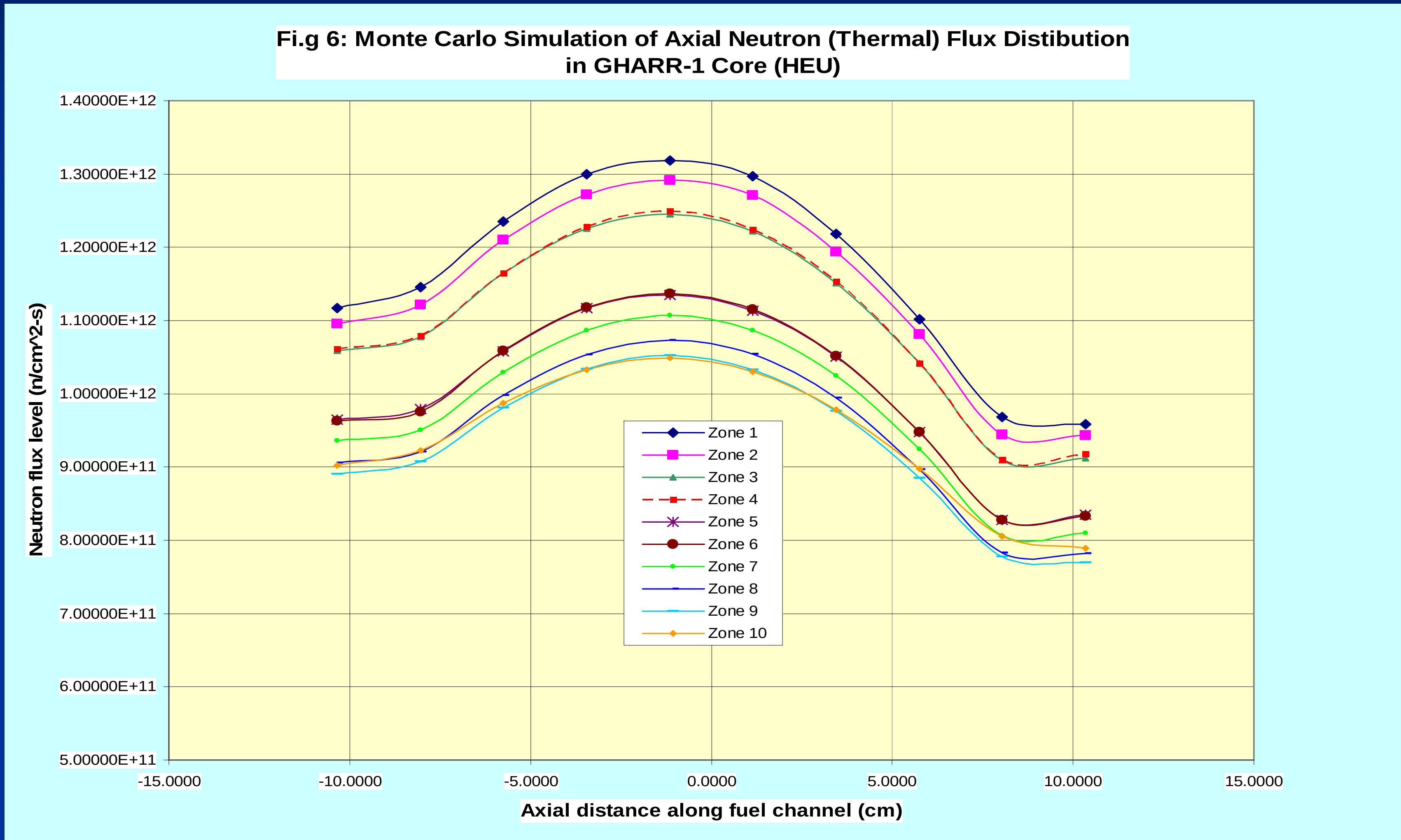
Results and Discussions: Power Distribution



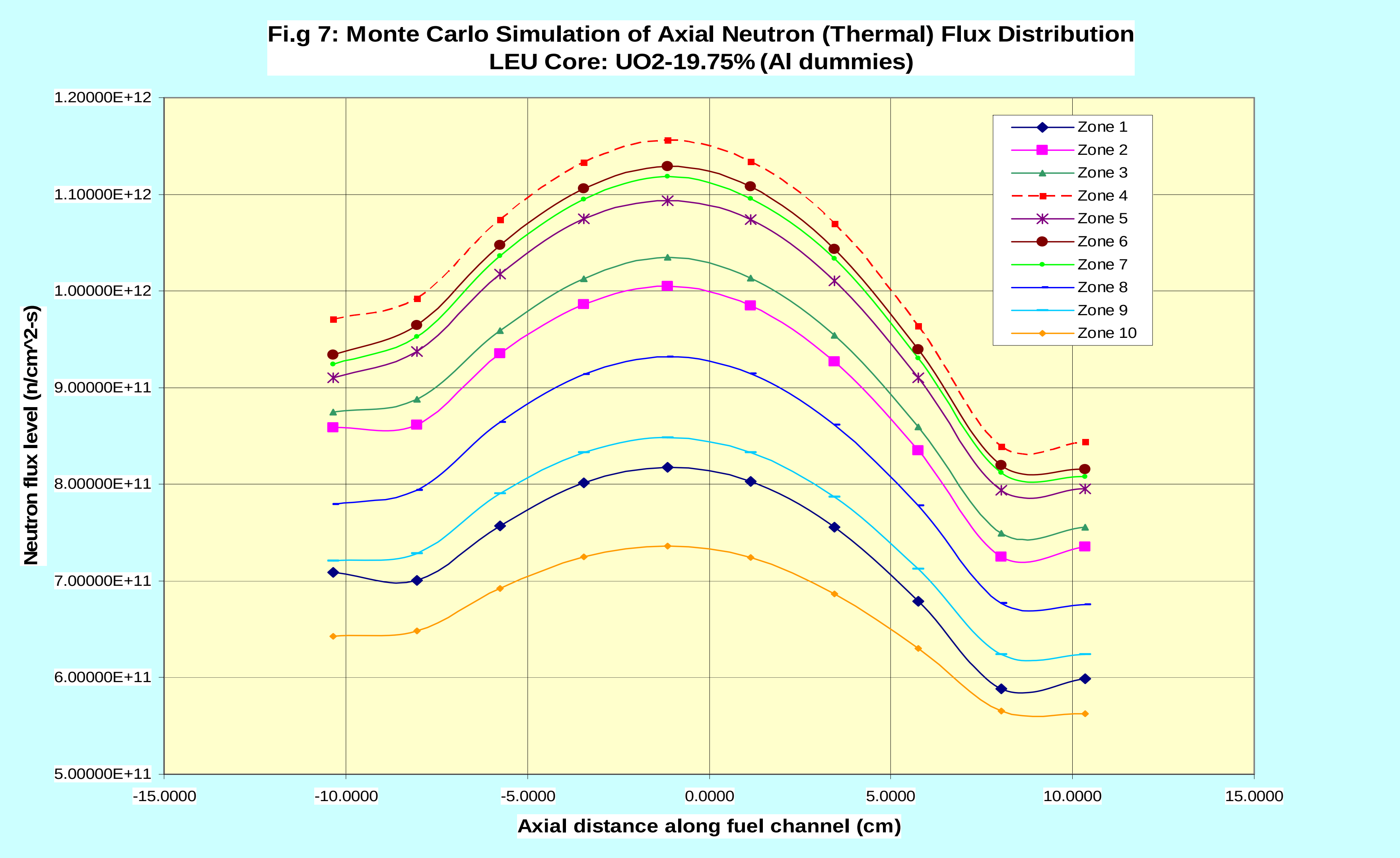
Results and Discussions: Neutron Flux Distribution (Reactor Core)



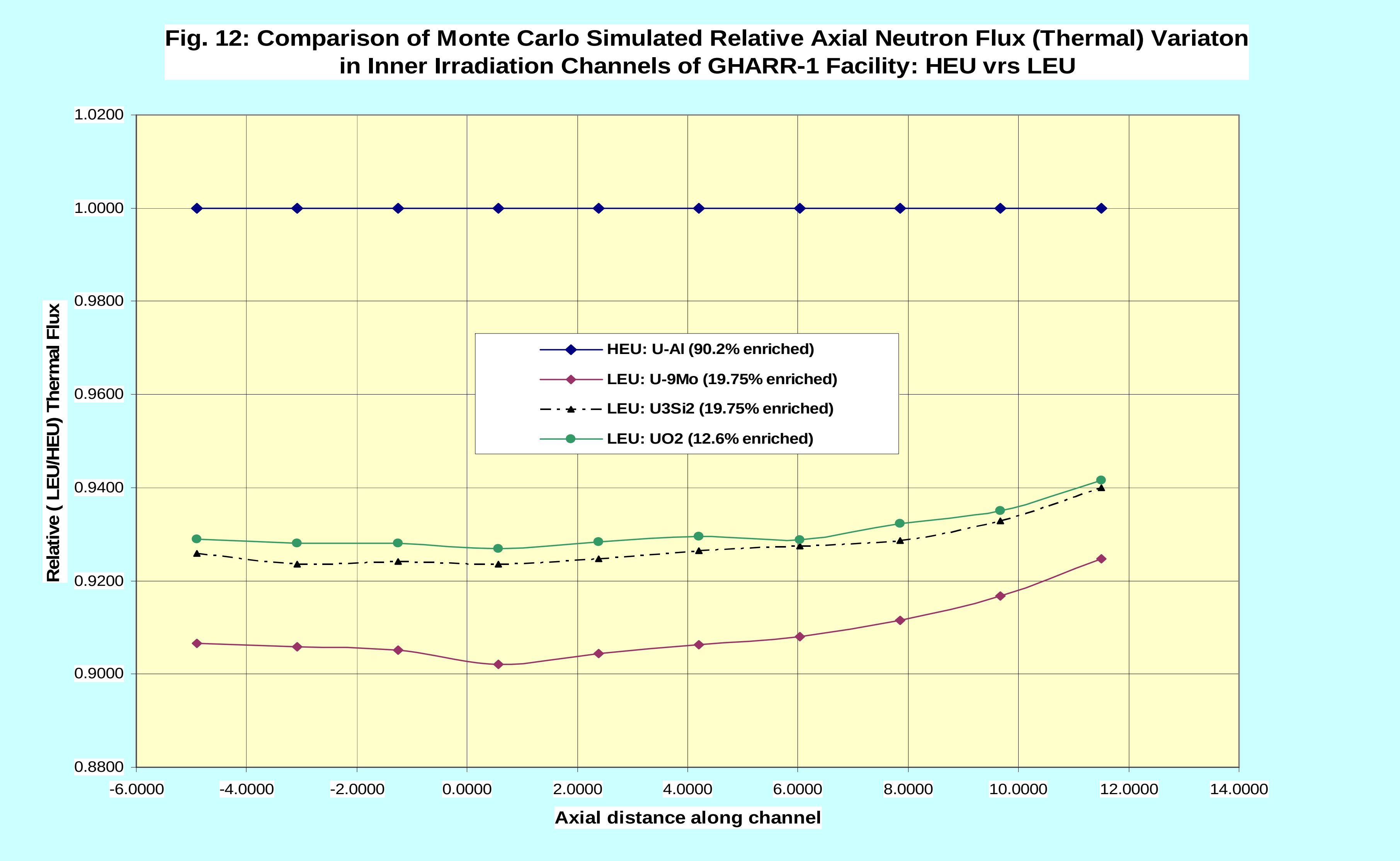
Results and Discussions: Neutron Flux Distribution (Reactor Core)



Results and Discussions: Neutron Flux Distribution (Reactor Core)



Results and Discussions: Neutron Flux Distribution (Irradiation Channels)



Results and Discussions: Kinetics

Fuel type	Nuclear criticality factors		Effective delayed neutron fraction	
	k_{eff} (total)	k_{eff} (delayed)	β_{eff} (MCNP)	β_{eff} EXT
HEU (U-Al alloy	1.00454	0.99618	8.3541E-03	8.0800E-03
LEU UO_2 12.6%	1.00454	0.99621	8.3240E-03	
LEU UO_2 (19.75%), Al	1.00481	0.99636	8.4402E-03	
LEU UO_2 (19.75%), W	1.00434	0.99609	8.2543E-03	

CONCLUSION

- A 3-D Monte Carlo model has been developed for the Ghana MNSR using the versatile MCNP particle transport code
- Model has proved to be very effective for global neutronics analysis and simulation of reactor physics design parameters of MNSR reactors, including HEU-LEU core conversions studies, as evident in its application to other MNSRs.

CONCLUSION

- Neutronic analysis based on the Monte Carlo transport approach has been performed for the 30kW (th) Ghana MNSR (GHARR-1) facility.

- In particular, the neutronics analysis has been extended to the GHARR-1 HEU-LEU core conversion studies.

CONCLUSION

- The Monte Carlo model correctly simulates the neutronics and other design parameters of the MNSR reactor, as seen from the demonstrated results.
- Results of the studies show that it is neutronically feasible to convert the MNSR reactors to LEU using UO_2 fuel with different enrichments and core configurations

ACKNOWLEDGEMENT

- National Nuclear Research Institute of Ghana Atomic Energy Commission for scientific and technical support
- RERTR Program of Argonne Nat'l Lab. for technical, scientific & logistical support – an EXCELLENT COLLABORATION!
- Excellent organization of the ENS+IGORR Int. Topical Meeting
- IAEA for moral and financial support for participation in this Meeting