Available online at www.elixirpublishers.com (Elixir International Journal)

Computational Chemistry

Elixir Comp. Chem. 43 (2012) 6556-6558

ISSN: 2229-712X

Prompt criticality studies and prompt neutrons energy spectrum flux profile of Ghana's miniature neutron source reactor core

B.J.B.Nyarko[1], R.B.M.Sogbadji[2], R.G.Abrefah[2], E.Mensimah[2], H.C.Odoi[2] and E.Ampomah-Amoako[2]

[1]Department of Nuclear Engineering, University of Ghana, School of Nuclear and Allied Science, P.O. Box AE1, Atomic Energy, Accra, Ghana.

[2]Ghana Atomic Energy Commission, National Nuclear Research Institute, P.O. Box LG80, Legon, Ghana.

ARTICLE INFO

Article history:
Received: 14 December 2011;
Received in revised form:
19 January 2012;
Accepted: 31 January 2012;

Keywords
Environmental samples,
Soil fertility studies,
Geochemical mapping.

ABSTRACT

If a nuclear reactor happened to be prompt critical - even very slightly - the number of neutrons would increase exponentially at a high rate, and very quickly the reactor would become uncontrollable by means of cybernetics. The prompt neutron flux spectrum of the compact core of the Ghana's miniature neutron source reactor (MNSR) was understudy using the Monte Carlo method. 20484 energy groups combined for all three categories of the energy distribution, thermal, slowing down and fast regions were modeled to create small energy bins. The moderator, the inner irradiation channels, the annulus beryllium reflector and the outer irradiation channels were the region monitored. The prompt thermal neutrons recorded it highest flux in the inner irradiation channel with a peak flux of $(1.2091 \pm 0.0008) \times 10^{12}$ n/cm^2·s, followed by the outer irradiation channel with a peak flux of $(7.9393 \pm 0.0056) \times 10^{11}$ n/cm^2·s. The beryllium reflector recorded the lowest flux in the thermal region with a peak flux of $(2.3328 \pm 0.0004) \times 10^{11}$ n/cm^2·s. The peak values of the thermal energy range occurred in the energy range 1.8939×10^{-08} MeV – 3.7880×10^{-08} MeV. The inner irradiation channel again recorded the highest flux of $(1.8361\pm 0.0301) \times 10^{09}$ n/cm^2·s at the lower energy end of the slowing down region between 8.2491×10^{-01} MeV – 8.2680×10^{-01} MeV, but was over taken by the moderator as the neutron energies increase to 2.0465 MeV. The outer irradiation channel recorded the lowest flux in this region. In the fast region, the core, where the moderator is found, the moderator recorded the highest flux as expected at a peak flux of $(2.9143 \pm 0.0195) \times 10^{08}$ n/cm^2·s at 6.961MeV. The inner irradiation channel recorded the second highest flux while the outer channel and annulus beryllium recorded very low flux in this region. The final k-effective contribution from only prompt neutrons is 0.9956, hence the Ghana MNSR not prompt critical

Introduction

To design a nuclear system properly, it is necessary to predict how the neutrons will be distributed throughout the system. Unfortunately, determining the neutron distribution is a difficult problem in general. The neutrons in a nuclear reactor move in a complicated path as result of repeated nuclear collisions.

To a first approximation, however, the overall effect of these collisions is that the neutrons undergo a kind of diffusion in the reactor medium, much like the diffusion of one gas in another. Since neutrons in a nuclear reactor actually have a distribution in energy, this distribution must be accounted for in the diffusion equation. Neutrons are emitted in fission with a continuous energy spectrum, and this distribution broadens as the neutrons are scattered in the medium and diffusion about the system, losing energy in elastic and inelastic collisions.

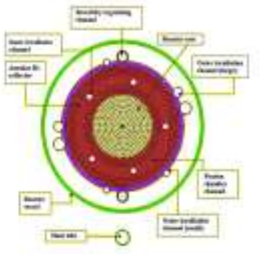
In nuclear engineering, a prompt neutron is a neutron immediately emitted by a nuclear fission event, as opposed to a delayed neutron decay which can occur within the same context, emitted by one of the fission products anytime from a few milliseconds to a few minutes later. If a nuclear reactor happened to be prompt critical - even very slightly - the number of neutrons would increase exponentially at a high rate, and very quickly the reactor would become uncontrollable by means of cybernetics.

The control of the power rise would then be left to its intrinsic physical stability factors, like the thermal dilatation of the core, or the increased resonance absorptions of neutrons, that usually tend to decrease the reactor's reactivity when temperature rises; but the reactor would run the risk of being damaged or destroyed by heat [1].

Design Considerations of Ghana research reactor-1

A detailed description of the operating characteristics of Ghana's MNSR has been presented elsewhere [2]. Table 1 shows the design specifications of Ghana research reactor-1. Due to its inherent safety features, stability of flux and moderate cost, the MNSR has recently found enormous application in various fields of science [3], particularly in trace elements in matrices of biological and environmental samples [4] and soil fertility studies and geochemical mapping [5]. Figure 1 shows the cross-sectional view of the Ghana research reactor-1.

Tele:
E-mail addresses: robertmawuko@yahoo.com



Theory:

The approximate value of the neutron distribution can be found by solving the diffusion equation. This procedure, which is called the diffusion approximation, was used for the design of most of the early reactors. One of the most effective ways to calculate diffusion of neutrons is by the group-diffusions method but the complexity of the group-diffusion or the *multigroup equations* as they are sometimes called, it is common practice to use a computer program to evaluate the group fluxes. The techniques by which this is done involve approximating the derivatives by numerical methods and then requiring the equation hold only at a series of discrete points in space. The equations are then reduced to algebraic equations valid for only those points. The exact approaches vary for each computer program. In this work, the Monte Carlo method was used for the simulations.

Method:

In recent times the Monte Carlo approach has been included to reactor analysis. In particular, multipurpose Monte Carlo particle transport codes generally have the capability to model and treat different complicated geometries in 3-Dimensions and also simulate the transport behavior of different particles and nuclear interaction processes. Good and accurate modeling of the different zones and diverse geometries of the MNSR reactor is important for realizing good neutronics, particle transport simulation, and physics analysis. For these reasons, the versatile and widely utilized MCNP code particle transport code was employed to develop a 3-D Monte Carlo model for MNSR for particle transport simulation and neutronic analysis of MNSR reactors [4, 11]. The 3-D GHARR-1 Monte Carlo model using the MCNP code was used to simulate some reactor physics parameters such as nuclear criticality and prompt neutron energy flux distribution of the GHARR-1 facility operating on 90.2 % HEU U-Al fuel. Neutron particle transport simulations were performed for a clean fresh core (zero burn-up) at room temperature. Criticality calculations were performed to determine *keff* and neutron fluxes at specific energy bins.

The Monte Carlo Approach

MCNP simulations were made for 500,000 neutron particles and 400 criticality cycles, corresponding to 200 million particle histories.

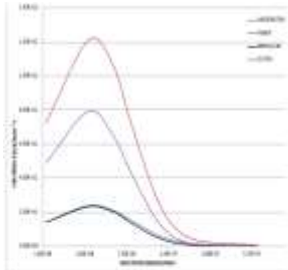
An initial criticality guess of k*eff* =1.004 was used in respect of the fact that the cores excess reactivity for the GHARR-1 HEU core is 3.99-4.00 mk. The MCNP criticality and neutronics simulations were normalized to the steady-state full power level of 30 kW corresponding to peak thermal neutron flux of 1.0 x 10^{12} n/cm^2·s (critical operation mode).

The MCNP neutron energy spectrum was performed for 20484 energy groups combined for all three categories of the energy distribution, thus thermal, epithermal and fast. The MCNP command "totnu no" was invoked to monitor reactions involving only prompt fission reaction.

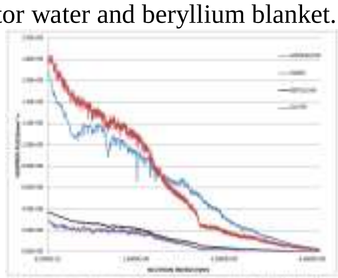
The following energy bins were used in the MCNP tally for the various energy groups; 1.89e-8MeV energy bin for (0 – 6.25e-7) MeV thermal energy range, 1.89e-3 energy bin for (8.21e-1 – 6.94) MeV slowing down energy range and 1.89e-3MeV energy bin for (6.96 – 20) fast energy range.

Results and discussion:

The keff contribution from the prompt fission flux of the Ghana research reactor -1(GHARR-1) was found to be 0.99556 ± 0.00007. The operating license of the k-effective of GHARR-1 is 1.004, hence the excess k-effective contribution is from delay neutrons. This phenomenon manifests the safety inherent feature of the miniature neutron source reactor. The k-effective contribution from the prompt neutron flux is less than one, hence the Miniature Neutron Source Reactor (MNSR) is not prompt critical.



In fig.2, it is observed that the thermal neutron flux in inner irradiation channels records the highest neutron flux at very low thermal energies. Due to the presence of light water and a beryllium blanket between the core and the inner irradiation channel, high flux of prompt neutrons from the core undergo enough collision to convert the high energy epithermal and fast neutrons into thermal neutrons in the inner irradiation channel. Due to the small size of the core, little moderation of neutrons takes place in the core because the reaction path is too short to produce enough collisions to reach the thermal energy range. The low thermal neutrons found in beryllium blanket and in the moderator are basically due to reflection of neutrons back into core by the reactor water and beryllium blanket.



In fig. 3, it is observe that, there is high flux of the slowing down neutrons of below 2.0 MeV in the inner irradiation channels than in the reactor moderator, this is due to the compact nature of the core, because most of the high energy neutrons above 2.0 MeV are slowed down to a lower energy as it get into the inner irradiation channel, hence the neutron flux in the reactor moderator at higher energies are more than that of the inner channel and any other location under study. This is where the prompt neutrons are born. The outer irradiation channel records the lowest flux because it's the furthest away from the core. The slowing down neutron flux energy spectrum profile in the beryllium is higher than that in the outer irradiation channel. This may be due to the fact that the beryllium reflector is closer to the core than the outer irradiation channels, so by the time the neutron gets to the outer irradiation channels they would have been moderated to lower energies than that are found in the beryllium reflector. The resonances in this energy range are due the fact that this region is close to the epithermal neutrons energy range.

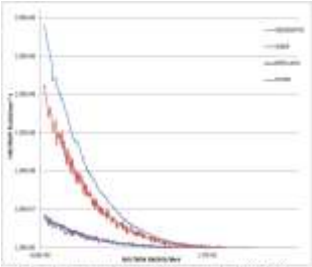


Fig.4 shows a continuation of the tail end of fig.3, the moderator records the highest flux in the high energy ranges because the neutrons are born in this region. In this energy region, due to the fast energies born by these neutrons, resonances are at a minimum. The inner channel records the second highest flux in this energy range because this channel is closest to the core. The beryllium as a reflector reflects some of the fast neutrons that were able to escape moderation back into the core thereby reducing further the fast neutron population. This explains the reason why the fast neutron flux in the inner irradiation channel is higher than that in the beryllium.

Conclusion:

The MCNP code has confirms the safety inherent feature of the miniature neutron source reactor designed by the Chinese is not prompt critical. This shows that the MNSR is safe to be used in universities and other institutions for scientific work where the construction of bigger research reactors will not be appropriate.

In addition, due to the compact nature of the Ghana miniature neutron source reactor, substantial amount of prompt neutrons flux of higher energies are present in the inner irradiation channel of the reactor. This discovery will help in the feasibility of performing experiments involving high energy neutrons, such as Epithermal and fast Neutron activation analysis. Though this compact core is cooled by natural convection, tremendous moderation of high energy neutrons is achieved by the water and beryllium moderators. Hence this reactor design, which can be installed in universities and will not occupy large areas, can also achieve a significant purpose of scientific work where large core research reactors are usually used.

References:

1. Lamarsh, Introduction to Nuclear Engineering
2. Akaho E.H.K., Maakuu B. T., Qazi M. K., Comparison for some measured and calculated nuclear parameters for Ghana Research Reactor-1 core, Journal of Applied Science and Technology, pp 25-31. 2000.
3. Kennedy G., St.Pierre J., Wang K., Zang Y., Preston J., Grant C., Vutchkov M., Activation constant for SLOWPLOKE and MNS Reactors calculated from the neutron spectrum and k0 and Q0 values, Journal of Radioanalytical Chemistry, p 167. 2000,
4. Su-De T., Multi-elemental analysis of Chinese Biological standard reference materials by Monostandard instrumental neutron activation analysis, Journal of Radioanalytical Nuclear Chemistry, p 81. 1984.
5. Umar I.M., The potentials of MNSR in the Socioeconomic Development of Nigeria, ICENSIAEA Small Research Reactor Workshop, University of West Indies, Jamaica. 2003.
6. United Nations International Nuclear Fuel Cycle Evaluation (INFCE), Report of INFCE Working Group 8: Advanced Fuel Cycle and Reactor Concepts, Vienna, 1980, p. 17
7. Balogun G. I., Jonah S. A., Ahmed Y.A., Sa'adu N. Results of On-site Zero-power and Criticality Experiments for the Nigerian Research Reactor-1, Internal Report CERT/NIRR- 1/ZP/01. 2004
8. Akaho E.H.K., Maakuu B.T., Anim-Sampong S., Emi-Reynolds G., Boadu H.O., Osae E.K., Akoto Bamford S., Dodoo-Amoo D.N.A. Ghana Research Reactor-1 Final Safety Analysis Report, 2003
9. Anim-Sampong, S., et al Progress in the Neutronic Core Conversion (HEU – LEU) Analysis of Ghana Research Reactor–1, 28th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR-2007) October 29 – November 2, 2007, Cape Town, South Africa.
10. Anim-Sampong, S., Akaho, E. H. K., Gbadago, J. K., Adam, A., Neutronic Analysis for Conversion of the GHARR-1 Facility using Monte Carlo Methods and UO_2 LEU Fuel, RRFM and Meeting of the IGORR, Centre de Congres, Lyon, France, 11-15 March, 2007.
11. Anim-Sampong, S., Progress Report, ANL RERTR Visiting Scholar (Research Fellow) ANL, USA. 2006 .

Table 1. Technical Specifications of Ghana's MNSR

PARAMETER	DESCRIPTION
Reactor design type	Tank-in-pool
Rated thermal power	30 kW
Excess reactivity	3.5-4.0 mk
Fuel	U-Al dispersed in Al
Enrichment	90.2 %, HEU
Diameter of fuel meat	4.3 mm
Diameter of fuel element	5.5 mm
No. of fuel elements	344
U-235 loading	~ 1 kg
Core diameter	23.1 cm
Core height (active)	23.0 cm
No. of irradiation channels	10
Inner channels	5
Flux in inner channel (peak)	1.0E+12 n /cm^2.s
Flux in outer channel (peak)	5.0E+11 n/cm^2.s
Reactor cooling mode	Natural convection
Height of inlet orifice	6 mm
Height of outlet orifice	7.5 mm
Length of control rod	230 mm
Reflector material	Beryllium metal alloy