



Low Enriched Uranium Dioxide: A Best Fuel for Miniature Neutron Source Reactor in Kinematic Parametric Calculation

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ABSTRACT

The alarming rate of variation results obtained from the day-to-day analysis especially the once that involved point kinetic parameters (the kinematic behavior of the neutron) of the Nigeria research reactor-1. The inconsistencies in the end-marks of the analysis became a horrible issue of great concern that might give wrong information and lead to a mechanical problem in the reactor. This research seeks to find out the reliability of the kinematic behavior of the neutron of the Miniature Neutron Source Reactor (MNSR) named Nigeria Research Reactor -1 (NIRR-1) using a simulation software named Serpent code 1.1.7 and Uranium dioxide as fuel of the reactor. The kinematic behavior of the neutron was observed through delayed neutron (l_d) and its related factors such as neutron power, reactivity, multiplication factor, control rod movement and its lifetime. The Serpent code was used to iterate the fission probability in determining the delayed neutron parameters of this reactor under one averaged generation time and neutron population rate. The calculated values of prompt neutron lifetime (analogue and implicit), reduction and emission time of the delayed neutron were all within the range of $(3.24 \text{ to } 3.33) \times 10^{-7}$ and have precision within the range of (0.005 to 0.035). In the near future, the results obtained on the delay neutron fraction and the time-based parameters would stand enough to guide for NIRR-1 modelling; hence the results described the dynamical and transient behavior of the delayed neutron in this reactor. In addition, results of this analysis spelled out the compatibility and relevance of low enriched uranium dioxide fuel in NIRR-1 due to the conformity of these results with the other results obtained on same reactor using Monte Carlo codes and high enriched uranium as fuel.

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INTRODUCTION

This paper intended to affirm that the knowledge of point kinetic parameters which relied on the behaviours of the delayed neutron (l_d) is a nexus for reactor core conversion. The delayed neutrons are the kinematic neutron in reactor system that tells more about many important parameters. The typical responses of delayed neutron and other related factors was used in determination of the point kinetic parameters for Nigerian Miniature Neutron Source Reactor that

was code named NIRR-1 after the name Nigeria Research Reactor -1. The Serpent 1.1.7 code was used for point kinetic parameters calculation using an iterated fission probability (IFP) [1], [2]. The other related factors calculated under this analysis includes multiplication factor (k_{eff}), reactivity (ρ), neutron power, reactor core lifetimes and control rod insertion. The average generation time and delayed neutrons (l_d) were used for determining point kinetics parameters, which gave raised to the determination of analogue prompt neutron



lifetime, implicit prompt neutron lifetime, reduction time and emission time of an average delayed neutron. These aforementioned five (5) neutron kinetic parameters were calculated on the bases of the neutron populations and the rate on which it multiplied. The rate of neutron populations is the difference between excess neutron produced by fission and the neutron lost by absorption. Hence time has no physical meaning in the relation, which defined the rate of neutron population but rather it depends on weighting functions, therefore the point kinetics parameters are basically observed to be entirely arbitrary. Meanwhile it was reported that point kinetic parameters of research reactors are approximately calculated under assumed constant flux shape, space and energy time dependence, first order of perturbation theory when it comes to calculate other factor like reactivity and inhomogeneous balance equation for independent neutron source reaction calculations [3].

In this analysis five parameters were determined under point kinetics, which are as followed: estimated prompt neutron lifetime for both analogue and implicit, estimated reproduction time for both implicit and analogue and emission time for an average delayed neutron [4], [5]. Similarly, this study intended to observe these point kinetics parameters in three (3) segment of the Nigerian MNSR by simulation. The segment of the reactor includes lattice, core assembly and pin-cell [6]–[10].

As it was obviously known the reactor in use needs or requires having proper maintenance, safety and control, hence with time it might developed a problem or falls into subcritical level that is when it's often in use continuously at decreasing multiplication factor. Therefore operating the reactor with a decreased multiplication factor below its standard value would automatically leads to a sudden problem, which is the change in the external source strength of the reactor. Perhaps, it would be a nexus for the next and more worth problem that

affect the reactivity of the reactor independent of any other external control. Moreover, this changed would force the neutron population to automatically move to a new different station, which indeed causes the reactor to develop a serious fault. Therefore, this necessitated and prompted to carry out the analysis and in order to ease and ensure the feasibility and compatibility of the fuel core conversion. The determination of point kinetic parameters is of course considered as the solution to all of these series problems because they are the parameters used for the analyses of reactors' critically condition. Similarly, point kinetic parameters are used in predicting or estimating the power of a reactor, hence are directly related to the reactivity of reactor and control rod insertion [11].

As it was reported that a slight change or deviation occurred away from the standardized values of reactor point kinetic parameters is confirmed to have a sudden changed in the reactors' flux shaping factor [10], [12], [13]. Even though, an over predicted neutron source transient trip data from the reactor is mostly happened as a result of a negative insertion which it would leads to have wrong results for the point kinetic parameters [14], [15]. The delimitation in this study was only to calculation the neutronic kinematic behaviour of the prompt neutron lifetime and its prompt production time. While limiting other related factors which might affects the kinematic behaviour of the neutron. The responses of the limited related factor are directly or indirectly depended on neutron fission probability time, which is not requested for this analysis. A licenced single user software named Serpent 1.1.7 code, developed by Radiation Safety Information Computational Centre (RSICC) team was used in carrying out this analysis. The software was offered to the researcher after accomplishing all the legal registration and satisfied all condition governing the releasement of the software.

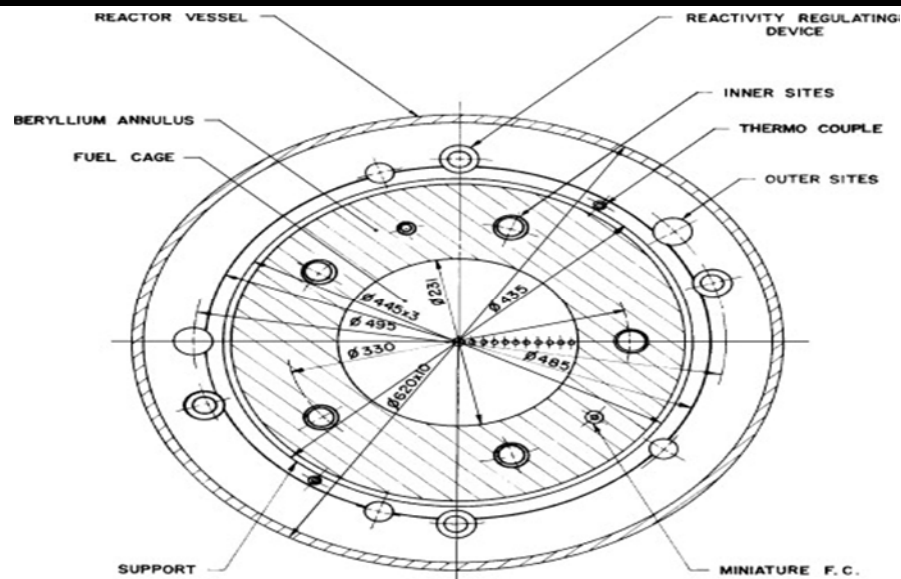


Figure 1: Transversal shape of NIRR-1.

Background

Many researchers have suggested and approved uranium dioxide fuel as the best and best fitting fuel for Nigeria research reactors unquestionably, due to the fact that the methodological tips followed to achieve this prefaced information are scientifically condone. Before the management of Centre for Energy Research and Training, Ahmadu Bello University Zaria to fully accept the use of uranium dioxide as fuel for its Miniature Neutron Source Reactor, it opened doors for more researches. Followed by recommending to the university to support the analysis that would backed the suggestion of fuel core conversion and to guard the reactor from misappropriate operations. The Figure 1 shows the transversal shape of NIRR-1.

It was in the light of this resolution condition and support. We were triggered to carry out this research that determined the point kinetics parameters of the Nigeria Research Reactor -1 (NIRR-1) using the Serpent 1.1.7 code. The software is a three-dimensional Monte Carlo code specifically designed for burn-up simulations and other related reactor physics calculation and applications. The choice of this code was behind the fact that the point kinetics parameters required

a continuous energy for its calculation and the Serpent 1.1.7 code operational energy is continuous energy. In addition, the Serpent 1.1.7 code has some important inbuilt functions that are used for some routines pattern of calculations or simulations, like generating multi-group constants for homogenization and other deterministic calculations and or reactor simulations [16]–[18]. In fact, the code can do all what a deterministic lattice codes did in better representation and reasonable time. Indeed the code stood-alone to simulate almost all of reactor regions such core assembly burn up, pin-cell burnup and fuel depletion among others. Another reason for chosen Serpent 1.1.7 code is that the point kinetic parameters calculations required a software that uses tallies in setting up an integral reaction rates for neutron transport simulation and uses the two tracking methods for lattice physics calculations and self-sustainable in sourcing information in case of reactor criticality calculations. The Serpent 1.1.7 code also has dual possibility of using both a conventional ray-tracing (surface-to-surface) and Woodcock delta-tracking method in lattice calculation and in solving depletion equations (Bateman) during pincell burn-up calculation. The two methods adopted in this analysis are



Transmutation Trajectory Analysis (TTA) and the matrix exponential solution, which is Chebyshev Rational Approximation Method (CRAM) respectively [19]–[23]. In this analysis the MPI, GD libraries, Graphic C-Compiler (GCC) and nuclear data libraries were used for the following reasons.

The overall calculation timing for the neutronics analysis is to long especially the point kinetic parameters. Therefore in this analysis the Message Passing Interface (MPI) was installed in order to reduce the period of the calculations. The MPI was used not only for hastening the simulation process but to adopt the use of parallelization mode [23]–[25]. Beside MPI an open source Graphics Data (GD) libraries are also installed for the Serpent 1.1.7 code to run analysis and compiled the parametric data successfully. Even though the source code functionally operates without GD and MPI [23], [26], [27], [28]. In addition, a standard GCC was incorporated, even though, by default, it was not conformant but for being the most fasten and standard than most of the open source compilers, such as Turbo C, DJ's GNU Programming Platform (DJGPP) and Borland C. The five different libraries used for this neutron parametric analysis are as followed ENDF/B-VI.8, ENDF/B-VII, JEF-2.2, JEFF-3.1 and JEFF3.1.1 [29]. All the aforementioned data libraries are mainly radioactive decay, fission yield cross-section and thermal scattering libraries. Some important cross section information used for this point kinetic parameter analysis were begotten from the data libraries and reconstructed and presented in Answer Cite Explain (ACE) format. Serpent 1.1.7 code has a recommended language which allowed the user to communicate via its interface although it is not user friendly. The language of the code was American National Standard Institute C-language (ANSI-C). The code was only runs and operates on a standard computers that has a memory of at least 5 GB. The Linux operating system was used on personal computer for carrying out this analysis. Even though, other operating system like Mac OSX and Macintosh (Apple desktop computer) can be used but on a Uniplexed Information and Computer System (UNIX) workstations.

EXPERIMENTAL METHODOLOGY

The research intended to simulate NIRR-1 reactor while operating with low enriched uranium fuel and to calculate the point kinetic parameters using a Serpent 1.1.7 code in order to ensure whether the fuel replacement or core conversion is possible and feasible or not. Therefore, parametric calculations in this analysis were carried out in three regions of the reactor, which involved the lattice region, pin-cell and core assembly out of the reactor configuration. In the same link the analysis would pave way for further modification or modelling the reactor configuration in whatever dimension if the need arises, hence the Serpent 1.1.7 code allowed such configurationally modelling for fast neutron and thermal systems reactors. Similarly, the code speeded up all calculation that uses single unionized energy grid [23], [30]. Basically, in a net shell the code was pivoted to calculate all physical interactions on kinematics classical collision and reaction laws used for evaluating fission nuclear data. Recall that the targeted reactor physics interaction which was intended to be determining among other standard reactor physics interactions concerning NIRR-1 reactor core conversion in this analysis was the point-kinetic parameters. The other standard reactor physics interactions includes homogenized reaction cross sections, effective multiplication factors, decay constants, infinite multiplication factors, assembly discontinuity factors, delayed neutron fractions, scattering matrices, precursor group and diffusion coefficients. As it was mentioned earlier that this analysis would be carried out in three regions of the NIRR-1 reactor (lattice, pin-cell and core), which unquestionably required here to describe the geometries and meshing the reactor regions in terms of their cells, surfaces and universes as in line with all standard Monte Carlo approach [33]. Therefore, the Serpent 1.1.7 code is used for other purposes such as educational training, group constant generation, demonstration, validation of other deterministic codes and fuel cycle studies [31]–[33]. The Figure 2 shows the longitudinal shape of NIRR-1.

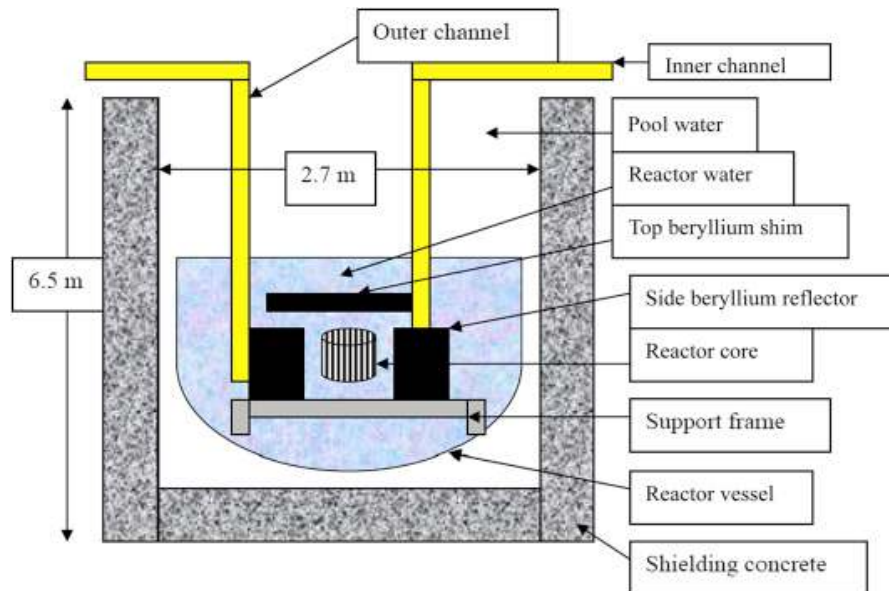


Figure 2: Longitudinal shape of NIRR-1.

Simulation

The ANSI-C programming language used by the Serpent 1.1.7 code makes life easier in all nuclear reactor simulation. Hence, all useful commands for installation and compilation of this nuclear data software were fully incorporated and accommodated. Therefore it was used for this analysis without incurring any problem or sending a message which identifies any error or saved as warning. Immediately, after a successful installation and compilation of the Serpent 1.1.7 code, this is for reactor physics burn-up Monte Carlo simulations. GD open graphics source libraries data and GNU Make File Utility (MFU) were then added onto the computer operating systems (OP) platform as instructed in the guide manure. The simulation of the NIRR-1 reactor was tested-ran to ensure every working principles are in order and to ensure the computer has the capacity for the target calculations. The Linux Operating System was found the best environment for the analysis point kinetics parameters. The reason for using Linux environment was that there were some intensive calculation in the analysis of kinematic parameters, which requires a computer with high computing power and adequate provision of memory spaces. In a nutshell, the line interface

command “sss” was used as executable command for running all the simulations concerning the point kinetic parameters calculations analysis for NIRR-1 [23], [34]–[37].

Moreover, in view to calculate the stated parameters, the study also focused to calculate the running time for each point kinetic parameters. The running time was calculated to determine if weather there would be any variation and to know its leading factor(s). For instance, the running time was calculated during simulation of NIRR-1 infinite-lattice on one of the workstation personal computer that has high computational power.

Hence for parametric analysis a large number of computer memories are required; therefore it was emphasized to use the Serpent 1.1.7 code, because it has a preferential impact on all time based calculations, which by default requires many memories due to its nature of characterization. At steady-state, the Serpent software was characterized to use a sizable number of computer memories especially for core assembly or pin-cell burn-up simulations. The unionized energy grids format was used throughout the process of analysing these point kinetic parameters [23], [28], [31]–[33], [38], [39].

Several input files and or a times single file were used for easy interaction and served as



an interface with which the user (we) communicated and passed or sent the unorganized information to the source code for interpretations and the expected outcome that describe the detail of the running-time. The main and optional input-files were named in accordance with their function and served as general syntax for an executional command for the point kinetic parametric analysis while simulating NIRR-1. In addition to main and optional files used, the standard text file was also used to describe the nature of the inputs within the input file. However, the input files are of two kinds, the main for commands and other referral file for easy and distinct runs of the programme. Indeed, the optional input files were used in conducting simulation of Nigerian miniature neutron source reactor to generate, calculate, run or run in parallel mode, disperse pebbles or particles that were randomly distributed in a given configuration using an optional file command 'disperse'. The optional input file 'check' were also used to check at random points the volume of pebbles or particles. Again, the option file 'test' was used for testing the geometry, surface and universe of a cell. The randomly sampled neutron were tracked and replayed with option files 'track and 'replay' respectively to exit the on-going simulation from using the previous random number seed. Then the optional file 'print' was used to print the current version of information and replayed it using the optional file 'replay' to force the Serpent 1.1.7 code to reuse again the same random number seed. The system timing of the computer was preferred and used in setting the random number seed in this analysis instead of manual timing and this was done to avoid using of separate seed files. The 'test' option of the input file was used to tracks and debugs the neutrons that were randomly sampled and plotted across the NIRR-1 geometries. Similarly, the option 'test' was used for ensure weather the neutrons were appropriately defined and located into the correct cells or else debug and replay. Then errors observed when the programme was set running are finally deducted using an input file option 'spot out'. While the interesting part of this Serpent 1.1.7 code was that it automatically detects all input

errors without any difficulty. Again an input-file 'fed' is a command used for calculating cell's volume and the geometries for both the simple lattice and pin-cells of the Nigerian MNSR, 'NIRR-1 reactor. While in the case of complicated geometries was calculated manually. However, in this research the geometrical volume of the entire segment of NIRR-1 reactor were homogenized. This homogenization was done to ensure the successful calculation of detector reaction rates, normalization and burn-up as reflected in the results [33].

EXPERIMENTAL RESULTS

The analytical results obtained for NIRR-1 point kinetic parameters using Serpent 1.1.7 code simulation are presented in sequence of pseudo random numbers which is in the same way other Monte Carlo codes used to presents. Indeed this code operates like MCNP2 and uses a fixed common seed value number to carry out the kinematic parameters analysis and to even run other related simulations instead of using different seed by default behaviour of Serpent 1.1.7 code. If it goes by its default behaviour, different seeds would be used on each and every assignment in the analysis so as to be run separately and hence produces different results entirely. Moreover, as a result of using a replay command line option as a seed in the input file instead of setting the seed manually, the manual override behaviour was totally eliminated in the whole process. Therefore the statistical accuracy in the analytical results was achieved due the use of 1 million random points, which is large enough to satisfy this requirement. The figurative results shows that the particles or pebbles were well randomly distributed within the desired dimension of NIRR-1 as presented in figure (N). These was achieved due to the fact that the geometrical dimensions of pin cells, lattice cells, assembly-core, particle data, packing fractions and their volumes are well and promptly defined in the input files. Shown in Figure 3a was the transverse geometric cell lattices dimension of NIRR-1 under core assembly simulation with Serpent 1.1.7 code. While Figure 3b was the fuels arrangement in the core assembly of this same reactor.

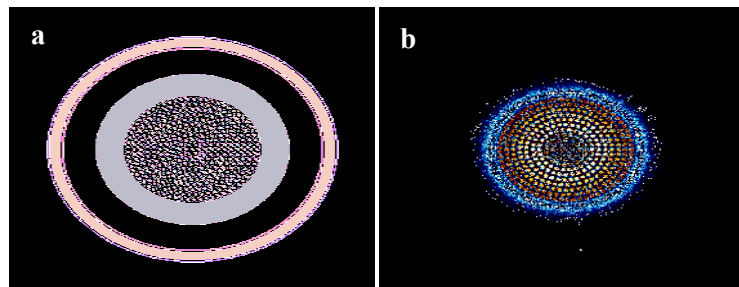


Figure 3a and 3b: Fuels arrangement in the core assembly of this same reactor.

Indeed the analytical results of these point kinetic parameters shown that the software used for this analysis, which was Serpent 1.1.7 code has advantage over other Monte Carlo codes because it overwrite the value of the old seed number each time the simulation was run with a new value of seed file instead to use replay option command [23], [37], [40].

The activation of the parallel option commands on the system was successfully achieved on the bases of installation and compilation of MPI libraries that was done using Make-file. The MPI means Message Passing Interface [23], [27]. The results for NIRR-1 point kinetic parameters calculations was obtained in both ways of the two parallel mode options command simultaneously and which it automatically reduced the computer running time. The geometrical representations of the results obtained and their changes as the need arises in this analysis was controlled by GD open source graphics library, which was installed on the

platform of the computer system to cater up any changes in compiler options within the Make-file [41], [42]. Therein, all the calculated point kinetic parameters values were checked in accordance to various activated pointer during this analysis. All unexpected results are drastically reduced and all errors were spotted through running the Serpent 1.1.7 code slowly before an inducement process. Any newly and poorly tested or detected features in the kinetic parametric results during the simulation were debugged using mode of debugging before reusing it again or compiled [43]. Similarly, the debugging mode with relevant associated libraries were also used to do away with all unexpected behaviour or crashed programme during the Serpent 1.1.7 code simulation before it recompiled and proceed or rerun again using gcc compiler instead of mpicc [23], [28], [31]–[33], [38], [39], [44]. The Figure 4 shows the nature of NIRR-1 pin cell after burn-up analysis.

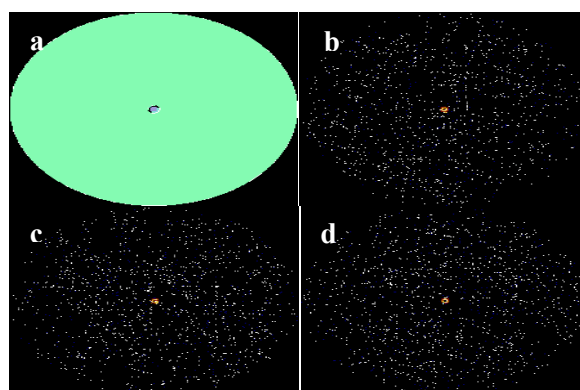


Figure 4: Shows the nature of NIRR-1 pin cell after burn-up analysis.



As suggested to use low enriched uranium fuel in all research reactors, therein in this analysis of point kinetic parameters, similar fuel is considered as the fuel of interest. The Serpent 1.1.7 was the code in place to determine the kinematic parameters of Nigerian Miniature Neutron Source Reactor (NIRR-1) while using low enriched uranium dioxide instead of its early high enriched fuel. The Table 1 shows that from this fuel analysis five parameters were found. The results in presentation indicated that all point kinetic parameters observed were in connected

directly to the kinematic behaviour of neutron atom out of the total components. Therefore the parameters observed are analog estimated prompt neutron lifetime (AEPNL), analog estimated reproduction time (AERT), implicit estimated prompt neutron lifetime (IEPNL), implicit estimated reproduction time (IERT) and average delayed neutron emission time (ADNET). These parameters are observed in three different region of the NIRR-1 reactor and these regions are core-assembly, lattice and in pin-cell as presented in Table 1.

Table Error! No text of specified style in document.: analysis.

Point kinetic parameters for Nigerian MNSR fuel

	Parameter (s)		Lattice	Core-assembly	Pin-cell
AEPNL	3.25×10^{-7}	3.36×10^{-7}		3.00×10^{-9}	
AERT	3.14×10^{-7}	3.30×10^{-7}		3.16×10^{-9}	
IEPNL	3.25×10^{-7}	3.37×10^{-7}		4.72×10^{-8}	
IERT	3.14×10^{-7}	3.30×10^{-7}		4.97×10^{-8}	
		ADNET	1.08×10^1	1.04×10^1	0.94×10^1

The Table 2 illustrated the values obtained from the outcomes of using the four different nuclear data libraries in determining the five kinematic parameters in the lattice region of NIRR-1 reactor. The nuclear data libraries used

includes ENDFB7, ENDFB68, JEF22 and JEFF31. The five kinematic parameters determined are AEPNL, AERT, IEPNL, IERT and ADNET.

Table 2: NIRR-1 lattice calculations of kinematic parameters with different libraries.

Parameters	ENDFB	ENDFB68	JEF22	JEFF31
AEPNL	3.26×10^{-7}	3.23×10^{-7}	3.33×10^{-7}	3.24×10^{-7}
AERT	3.14×10^{-7}	3.12×10^{-7}	3.16×10^{-7}	3.15×10^{-7}
IEPNL	3.26×10^{-7}	3.24×10^{-7}	3.33×10^{-7}	3.24×10^{-7}
IERT	3.14×10^{-7}	3.13×10^{-7}	3.17×10^{-8}	3.24×10^{-7}
ADNET	1.04×10^1	1.05×10^1	1.12×10^1	1.29×10^1

Related Result Validations

In this study a single-processor and predictor-corrector were used to calculate the running time of NIRR-1 point kinematics parameters in its lattice region. The result was in agreement with that of Light Water Reactor (LWR) core-assembly burnup simulated result, in which millions of neutron was found to overcome a single transport cycle in few hundred of minutes [19], [22]. Even though, there were some variations in the number of steps observed between NIRR-1 and that of LWR calculations but by the help of the predictor-corrector a better precision is

established in this analysis. Because more than two hundred nuclides of actinide appeared in the result and fission product and some depletion are encountered zones as well unlike in this analysis. The input file option used in this analysis was verified and validated to ensure that the volumes of all neutronic point kinematic parameters was correctly checked before running to simulate the program [31]–[33], [38], [39]. Since point kinetics parameters are directly associated with delay neutrons in all reactor system going by the theory and manufacturer's expectation and are time dependent parameters that are calculated under

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one averaged generation. Therefore, it would be more cogent if these parameters are validated with a calculated value of delayed neutrons (λ_d) which is also a time dependent parameter. Indeed it was validated with a calculated value of delayed neutrons (λ_d) obtained from same reactor but simulated with different Monte Carlo based codes. This validation supported the preference of low enriched uranium dioxide (UO_2) as fuel for NIRR-1 instead of its' former fuel, which was of high enriched uranium. Similarly in reference to world resolution on fuel technology the results of this analysis tent to be acceptable for it has being operably fit to the satisfaction of the world nuclear organizations' goal and achievement as well. It is in turn therefore suite as yardstick for the implementation of NIRR-1 reactor core conversion feasibly. Moreover the delayed neutron was eventually effected the typical responses of the kinematic neutrons of NIRR-1 in relation to its neutron lifetime, reactivity (ρ), control rod movement, effective multiplication factor (k_{eff}) and neutron power. In one side, measures were taken to overcome these effects caused by delayed neutron. A slight change in reactivity factor might lead to re-predict the reactor power to avoid any underestimation. Aging any unfavorable movement during control rod insertions the reactor criticality level might raise or falls and become uncontrollable the transient trip of the neutron source is readjusted. The NIRR-1 point kinetic parameter was calculated under an assumed separable time-dependent variables and constant flux shape. The result was in agreement with a valid approximated first order perturbation theory. Henceforth, by valid observation when an independent neutron source is used for calculating kinematics parameters, reactivity or balancing up the inhomogeneous neutron reaction equations, the separable time-dependent variables would also be used in the first order perturbation theory.

The simulated point kinetic parameters results obtained from this analysis indicate that there is vital linkages with effective multiplication factor and delayed neutron fraction and prompt neutron generation time of NIRR-1 reactor for being time dependent parameter. Therefore the used of uranium dioxide which is low enriched fuel as Nigeria research reactor fuel shows good

precision, conformity and also valid hence the system of the reactor usually attained its criticality when the time dependent parameters falls into lower values of its range as reported by some researchers on two MNSR (GHARR-1 and BWR). Even though for Ghana reactor, the neutron kinematic behaviors are determined using MCNP and MCNP5 with values of 8.1×10^{-5} s and 8.03×10^{-3} s, respectively [45], [46] while for BWR reactor, the effective delayed neutrons, absolute delayed neutrons and neutron generation time are determined using track length and the values for BWR are 7.44×10^{-3} , 7.15×10^{-3} and 2.43×10^{-5} respectively. In addition, researchers have conducted many researches in view to determine the point kinetic parameters with different statistical variance such as collision flux estimator, which involved delta-tracking. All the results are in good agreement with the result this analysis. Finally, all along four different nuclear data libraries were used each and repeatedly to ascertain the validity of this result. The nuclear data library includes ENDFB7, ENDFB68, JEF22 and JEFF31. Therefore the results the five point kinetic parameters calculated for Nigerian MNSR in its different regions (lattice, core and pincell) [47]. Therefore there were precision in the results because it doesn't exceed the mean number and the deviation from the mean was insignificant. The result obtained for ENDFB7 was 0.005, ENDFB68 was 0.035, JEFF31 was 0.025 and JEF22 was -0.065.

DISCUSSION

The variations observed in the running-time values of the five point kinetic parameters in this analysis were due to different physical interactions the neutrons are encountering during the simulation analysing of the NIRR-1 reactor. The parametric running-time values are directly related to the reactor regional configuration or complexity nature of the reactor. Indeed, running-time varies with nature of neutron interactions. In the infinite lattice calculation for NIRR-1, the running-time are in multipole and last for about twenty minutes. Almost millions of neutron were counted and classified as two-dimensional problems, which demand higher computer operating system with either single or double



processors. Vividly, the values for the running-time obtained with Serpent 1.1.7 code was found to be relatively faster compared to that calculated using other Monte Carlo based codes. The NIRR-1 point-kinetic parameters calculated under this analysis describes the neutron dynamical nature and its' operational transient behaviour within the limited range of multiplication factor. Indeed, this analysis it computationally portrayed the kinematic behaviours of neutron in all miniature neutron source reactors across the world. The analysis also established that the MNSR reactors are conveniently operable provided the running-time values of the kinematic parameters are in good agreement with other kinetic parameters. In another hand, the analysis supported the resolution on MNSR reactor's fuel core conversion the MNSR from high enriched uranium to low enriched uranium one, which was the commensurable uranium dioxide (UO_2). Of course, the results of these parameters was considered as the core-based of the reactor's performance, especially, when reactor attained to its subcritical level [48]. It further discussed that the knowledge of these point kinetic parameters gave an insight on how efficient and useful the low enriched uranium fuel and the fuel technology are in reactor physics and its maintenance. Then the results specifically emphasized the use of time-independent parameters like reactivity and neutron source in reactor calculations due to accuracy and efficiency observed in reactor system analysis [13].

The point kinetic parameter results sell-out the efficacy of the uranium dioxide as the best ever tested fuel that was so low enriched, qualitative and proved to maintain the functionality of NIRR-1 reactor system to its statorscope after the core conversion. The function of the reactor goes with its low range values of the multiplication factor and the suitability of point kinetic parameter. Indeed, the experiment was sufficient because a single problem pertaining the neutron kinematic behaviour was not detected from all fission probability iterations made in the analysis Now with this development for reliable and precise result obtained from NIRR-1 simulation and facts that kinematic parameters determination, was achieved is enough to generalise that the

feasibility of uranium dioxide fuel is quite appreciable. The world nuclear regulatory authorities have every reason to permit and grant the use of low enriched fuel over all other and similar reactors. Even though, going by the theoretical order of calculating point kinetic parameters for thermal reactors we observed that the NIRR-1 results obtained from this analysis have derogated small but still within the acceptable bracket. The insignificant deviation in few parametric values of the calculated point kinetic parameters of NIRR-1 has no any meaningful effect on the reactor system. Hence experimentally, these parameters depend on the weighting functions that cause such a sudden change in flux shape. Therefore, the result showed that the NIRR-1 reactor can still operate provided the values is below its supercritical but within its criticality level. Finally, the results from the three regions of the Nigerian MNSR showed that are in conformity.

CONCLUSION

This analysis exposed what were in cocoons regarding the knowledge of fuel technology in Nigerian. In near future on the basis of academic needs, the knowledge of using well-articulated Monte Carlo based code like Serpent 1.1.7 would become more available. The modelled results of the delayed neutron fractions and its time-based parameters for NIRR-1 now stands enough to guide the modelling and core conversion of other similar research reactor especially the MNSR once with similar characteristics. Moreover, the results spelled out the relevance, importance and compatibility of low enriched uranium (uranium dioxide) as fuel for reactors over high enriched uranium fuels in respect of the type of reactor. The point kinetic parameters result are in good agreement with parametric results obtained from NIRR-1 and similar miniature neutron source and the even more complicated reactors although Monte Carlo codes varies [47], [49], [50].

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