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Monte Carlo Method:
Theory and Exercises (4)

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Monte Carlo simulation of a TRIGA source driven core configuration: Preliminary results.

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Abstract

The different core configurations with a k_{eff} ranging from 0.93 to 0.98, and their response when driven by a pulsed neutron source were simulated with MCNP4C3 (Los Alamos - Monte Carlo N Particles). Simulation results could be considered both as preliminary check for nuclear data and a conceptual design for "source jerk" experiments on the frame of TRIGA Accelerator Driven Experiment (TRADE) on the reactor facility of Casaccia research center.

Introduction

Monte Carlo simulation on neutron Time of Flight spectroscopy (TOF) [1-2] is benchmarked and well-established task in experiment design and in nuclear instrumentation set up. The main difficult in the implementation of Monte Carlo time dependent techniques of neutron transport in a fissionable media was due to the lack of nuclear data on secondary production of neutron from fission fragments (delayed neutrons). The newest release of MCNP code (Los Alamos Monte Carlo N-particles ver. 4C [3]) is able to produce a more accurate simulation of the secondary production of neutrons from fission [4] by using a new data library [5] containing the relevant delayed neutrons information. These new features were tested on a simple and accurate experiment [6]. Aim of present work is to investigate on the complex simulation of a sub-critical TRIGA core configuration driven by an external suitable time shaped neutron source. The result can be regarded as a preliminary study in the implementation of a simulation tools for the design of the nuclear instrumentation for the TRIGA Accelerator Driven Experiment (TRADE) [7].

Methods and Schemes of calculations

Material and geometry

The entire geometry (see **fig.1**) of TRIGA core, graphite reflector, irradiation channels and pool was defined as MCNP input.

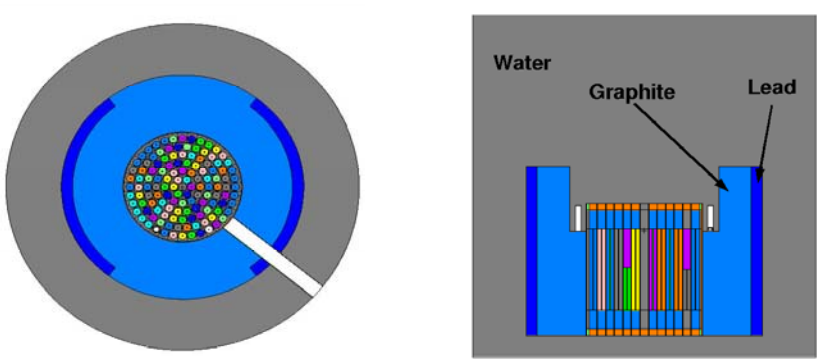


Figure 1. Horizontal and vertical cross sections of the TRIGA model as obtained by the MCNP plotter routine.

The control rods positions were simulated by a floating boundary between absorber and fuel follower (see **fig. 2**).

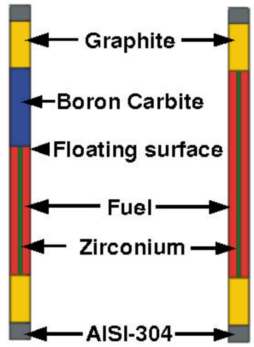


Figure 2. Control and fuel rods in the TRIGA model

The nuclear properties of the materials are defined by ENDF-B VI continuos microscopic cross sections data. Correction for the binding effect on thermal neutron scattering of light elements was also introduced. The delayed neutron generation in the fuel rods was also taking into account.

Critical reference configurations

The fuel of the core model was arranged in the same configuration (n° 235) of the 1 MW TRIGA Casaccia reactor. Two distinct inputs were prepared with temperature fields and control rods set-up relative to 20 Watt and 1 MW criticality respectively, no burn-up effects was taken into account. In both cases the k_{eff} convergence was achieved by iterative refinement of the fission source. The results were reported in **Table I.**

Table I

20 Watt Crit.	k_{eff}			
Calculated	1.00972 ± 0.00044			
1 MWatt Crit.	k_{eff}	$\phi_{central\ thimble}$	ϕ_{rabbit}	P_{Max}/P_{Av}
Calculated	1.00309 ± 0.00068	1.86e13	4.30e13	1.57
Experimental	1	1.91e13	6.35e13	1.55

Comparison of the model results with the experimental values. Fluxes are given in n cm^{-2} sec^{-1}. No burn up was taken into account in the calculations.

Sub-critical configurations

Three different levels of sub-criticality were achieved removing the fuel rods from ring B (fig. 3) and setting the control rods in different positions.

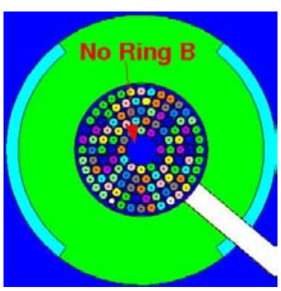


Figure 3. Sub-critical configuration without fuel rods on ring B

As index of the sub-criticality level a MCNP kcode run of each configuration was executed. Results are summarized in Table II**.**

Table II

SHIM1 (C7)	SHIM2 (C4)	Safety (C10)	k_{eff}	M
100%	45%	100%	0.9806±0.0007	30
40%	0%	100%	0.9602±0.0007	14
0%	0%	0%	0.9308±0.0008	8

Estimated level of sub-criticality (KCODE) for the three configurations without ring B: control rods insertions are reported as percent of fuel follower in core. M is the net multiplication factor (averaged number of neutron for source neutron) as furnished by MCNP output.

Time dependent simulations

An isotropic neutron source with gaussian energy spectrum (mean=14 MeV, σ =0.8 MeV) was located in the core center and transport calculations in the core multiplicative media were executed. The general characteristics of the source are similar to a Deuterium-Tritium neutron source. Two source time dependent behaviors were employed in the calculations (see fig. 4): an impulse (delta) emission and a source jerk like emission. No thermal feedback effect was taken into account in the calculations.

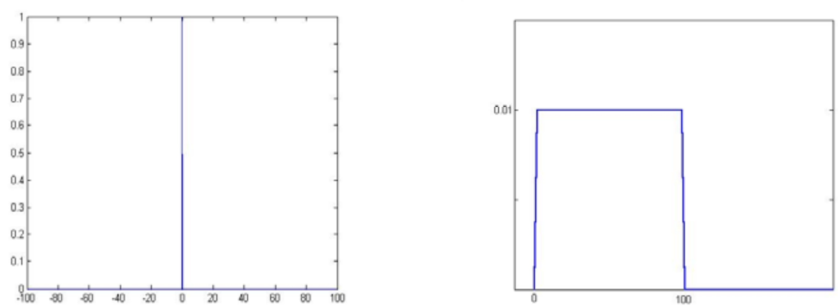


Figure 4. Time behavior of the neutron source: a) Delta shaped source. b) Source jerk like source.

The former was applied only on the configuration at k_{eff}=0.98 and the latter on all the three sub-critical cases. In each run fission and flux tallies versus time were accumulated on all fuel rods. In all cases $2x10^6$ source neutrons were employed. Typical running times are of 32 hours on cluster of 12 Compaq alpha processors.

Results and conclusions

The tallies data versus time for each configuration were reported in figures 5 to 9. For the delta shaped source driven system (see fig. 4a) the total neutron flux-time response at fuel rod C1 (k_{eff}=0.98) is reported in figure 5. The C1 flux shows from 10^{-3} to the 2 x 10^{-2} sec a decay originated by the decrease of the prompt fission then a constant flux value was sustained by delayed fission until t = 1sec, after which the flux continue its decrease. The prompt flux rise at very short times (10^{-5} sec) is not visible because of the tally time bins granularity. In the three cases concerning with the different sub-critical core configurations, in the neutron source jerk (see fig. 4b) case, fission powers versus time (from 0 to 600 sec) were reported along the fuel rods traverse C11, D16, E21, F26, G31 (figs. 6 to 8). The progressive departure from criticality differentiates the shape of the fission rate-time answer: the more the system approach criticality, the slower is the reaching of the stationary state and the longer is the decaying tail after the source shutdown. To investigate these features on quantitative basis a more accurate calculation with a particular refinement of high time (decay) bins is requested. Because of the massive demand of calculation power the same task could be performed at high precision by a run on delta shaped source response followed by a numerical convolution with source-jerk time shape of the so obtained tallies. Figure 9 reports the neutron spectra comparison immediately before (t≈90 sec fig. 9a) and after (t≈150 sec, fig. 9b) the source shutdown. As expected the 14 MeV peak, that belong from source uncollided flux, disappear after shutdown. All the results seem to confirm that MCNP time dependent model of the TRIGA source driven system is very promising tool to gain information on the sub-critical features of the system. The most attractive perspective is to develop a method capable of isolation of the fundamental harmonic from the superior ones in order to obtain the optimal location of instruments for in core measurements.

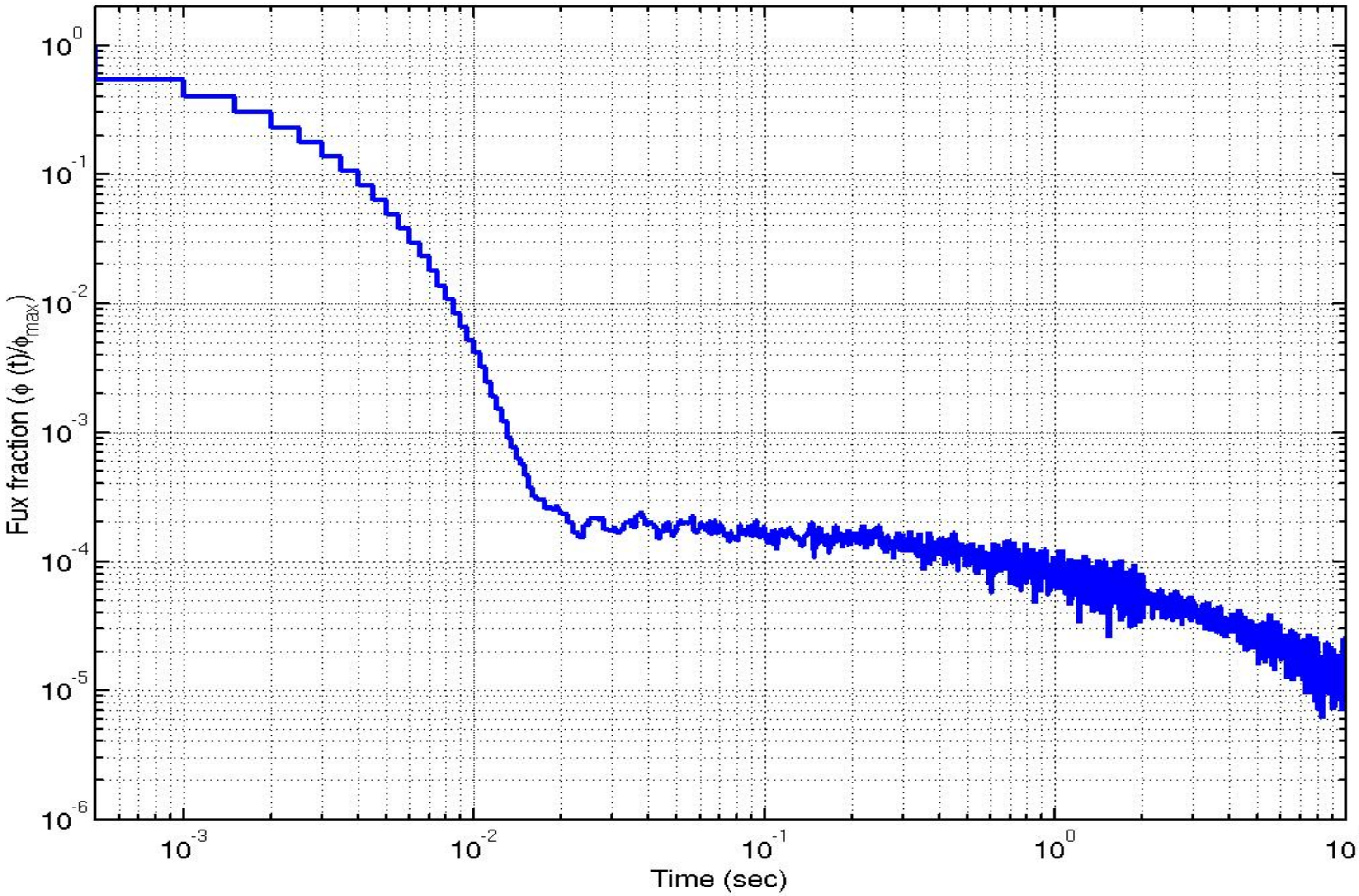


Figure 5. Flux versus time response at fuel rods C11 after a delta peak emission from source (k_{eff}≅0.98). The buffering contribution of delayed neutron to sustain flux is clearly visible.

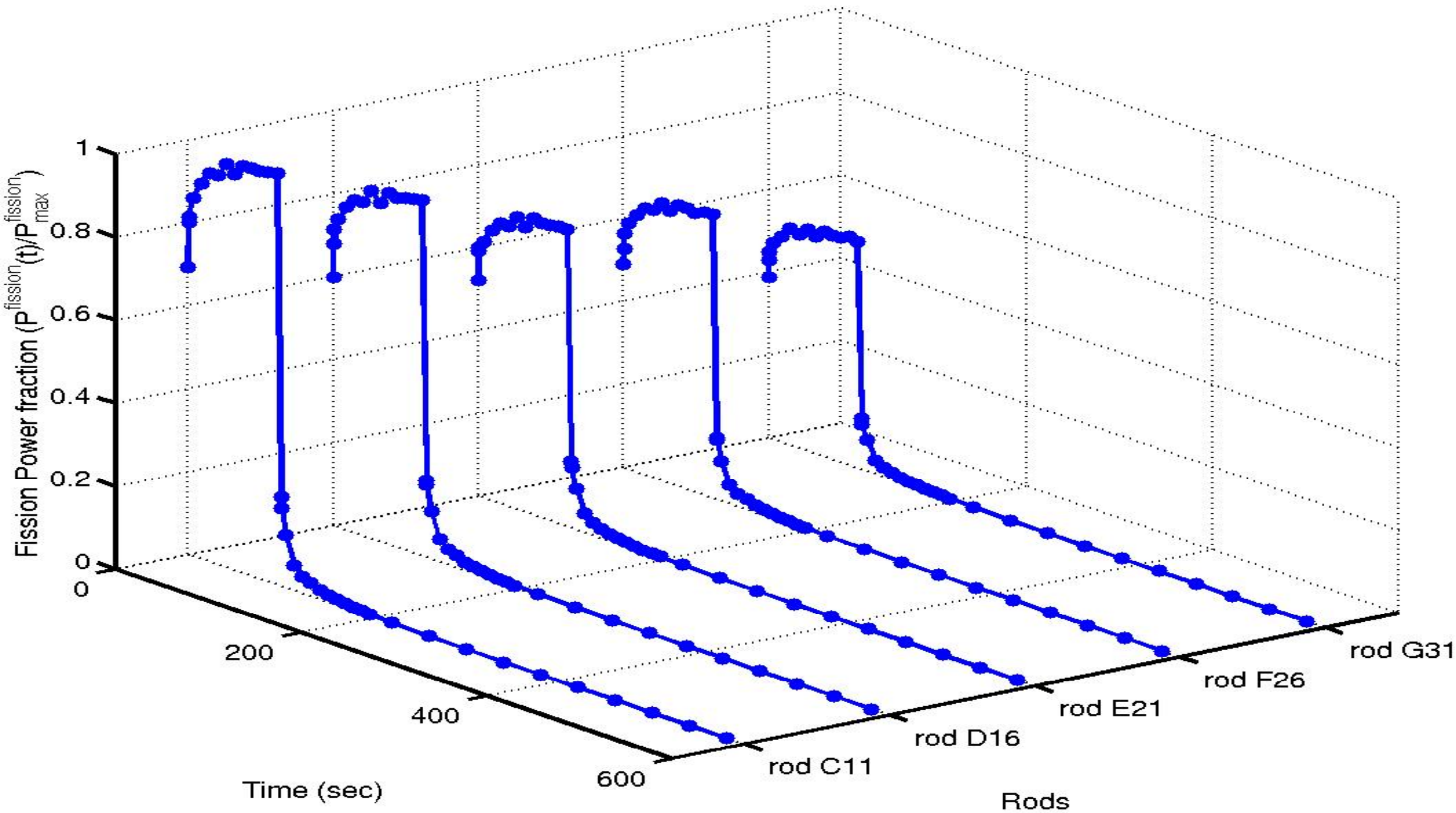


Figure 6. Fission Power Fraction along the fuel rods traverse (C11, D16, E21, F26, G31) vs time. k_{eff} ≅0.98, net multiplication factor M=30. Fission power were normalized on the hottest pin fuel ($5.304*10^{-1}$ MeV/s.p. C12)

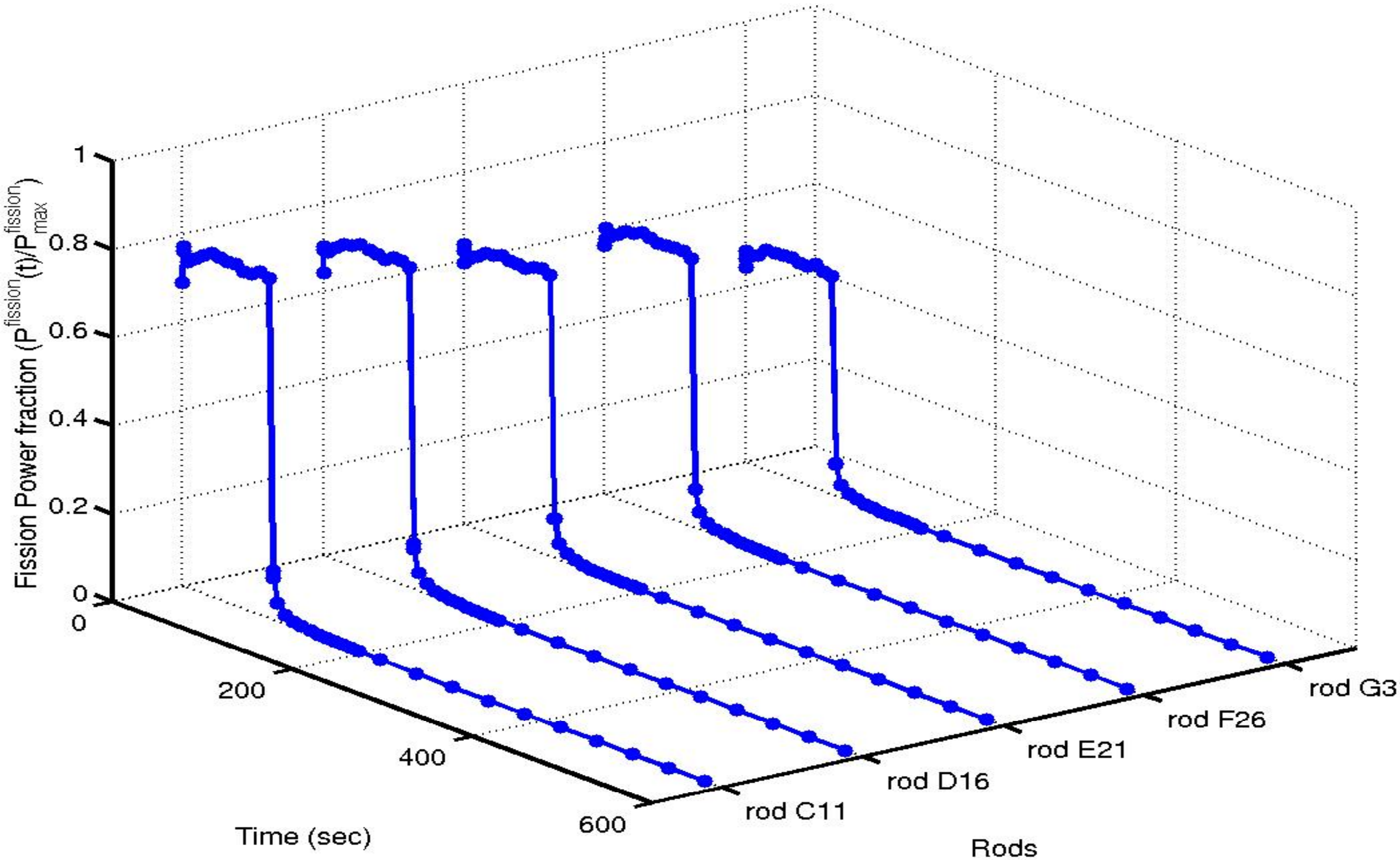


Figure 7. Fission Power Fraction along the fuel rods traverse (C11, D16, E21, F26, G31) vs time. k_{eff} ≅0.96, net multiplication factor M=14. Fission power were normalized on the hottest pin fuel ($2.48*10^{-1}$ MeV/s.p. C4)

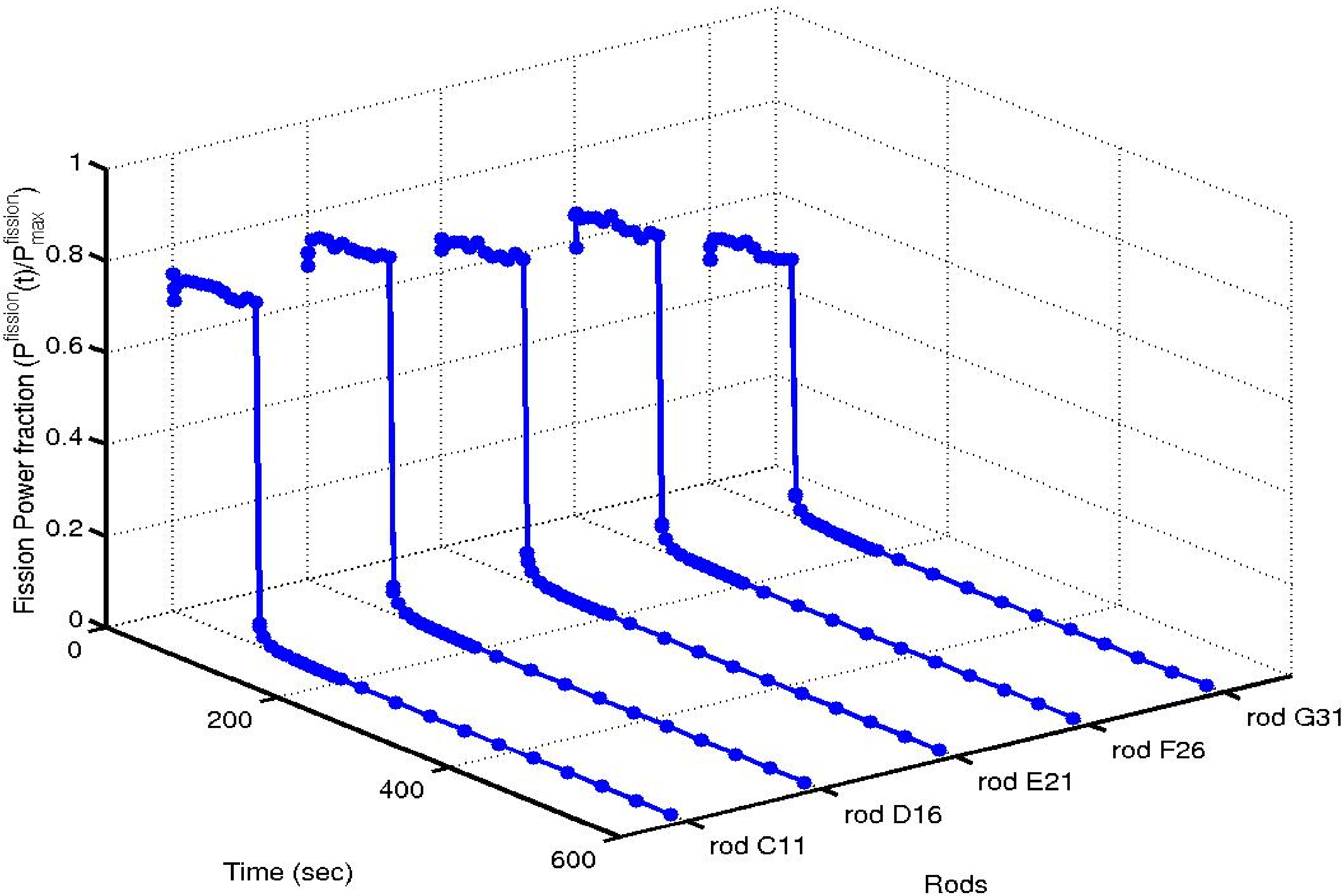
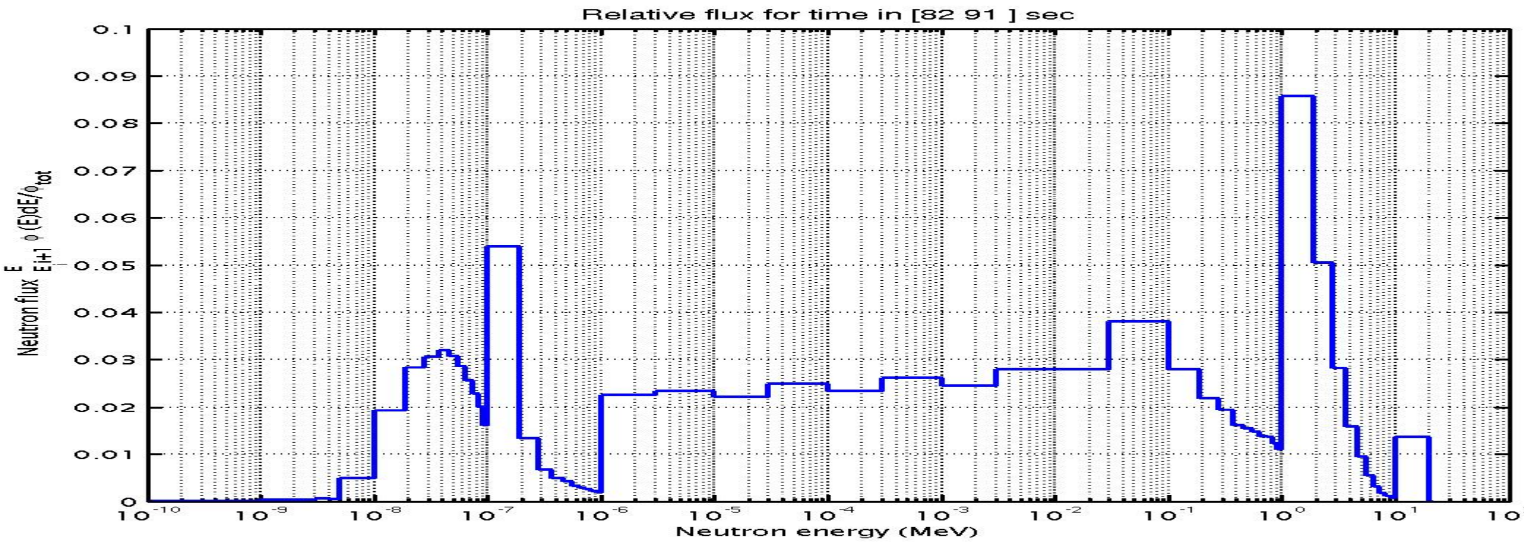


Figure 8. Fission Power Fraction along the fuel rods traverse (C11, D16, E21, F26, G31) vs time. $k_{eff} \cong 0.93$, net multiplication factor M=8. Fission power were normalized on the hottest pin fuel ($1.41*10^{-1}$ MeV/s.p. C12)



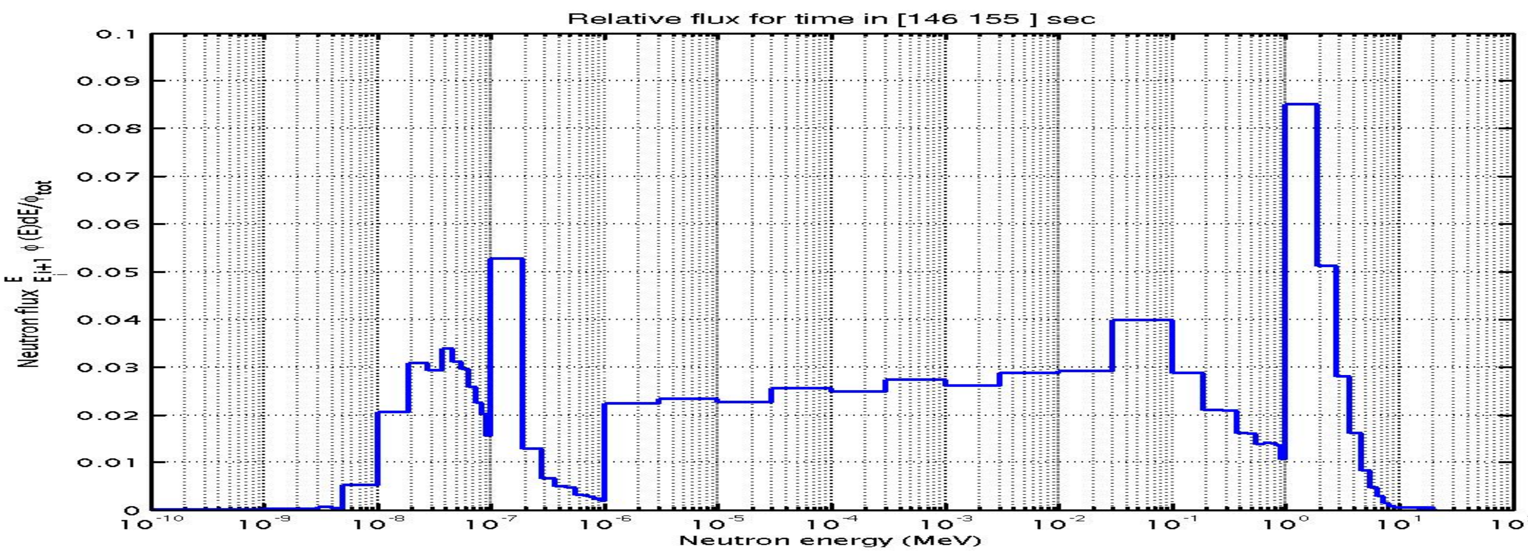


Figure 9. Neutron spectra in fuel rod C11 at time t≈90 sec (upper figure) and t≈150 sec (lower figure) for k_{eff}≅0.98 TRIGA assembly: Source jerk like calculation.

References:

[1] Mead, William C. (2000), "Assessment of Neutron and Gamma-Ray Scattering Background in the NIF Target Chamber for a Proposed Capsule ρr Diagnostic", ANSR report.

[2] D. J. Whalen, D. A. Cardon, J.L. Uhle, J. S. Hendricks (November 1991), "MCNP: Neutron Benchmark Problems", Los Alamos National Laboratory , LA-12212, Problem 1 pag. 6.

[3] Briesmeister, J.F. (Editor) (2000),"MCNP4C – A General Monte Carlo N-Particle Transport Code", Los Alamos National Laboratory report, LA-13709-M.

[4] Werner,C.J. (1999) "modifications for MCNP4XT to Include a Delayed Neutron Treatmen for Secondary Neutrons Produced from Fission", Los Alamos National Laboratory Memorandum, XCI:CJW-99-94.

[5] Werner, C. J., "New data library for MCNP delayed neutron capability", Los Alamos National Laboratory, Memorandum XCI:CJW-99-25.

[6] Werner, C. J. (2000), "Simulation of delayed neutrons using MCNP", Los Alamos National Laboratory, MS F663.

[7] TRADE working group (March 2002) , " TRADE Final Feasibility Report", Ch. 11 pag. 126-134.