LA-UR-

Approved for public release;
distribution is unlimited.

LA-UR 02-0044
c.1

Title: Fission with Cold Neutrons

Author(s): Rene Sanchez

Submitted to: To **be** presented at the American Nuclear Society (ANS) Conference, Holliwood, FL, June **19-1**3, 2002

Fission with Cold Neutrons

by

Rene Sanchez

Introduction

As NASA continues the exploration of deep space, there is a need for safe, reliable, and long-lasting source of energy. Solar cells, which are useful at the inner solar system, cannot provide adequate power for a spacecraft once it has passed beyond Jupiter's orbit. For missions to the outer planets, NASA has relied on radioisotope thermoelectric generators (RTGs) using ^{238}Pu as a heat source. RTGs are an excellent power conversion technology but, unfortunately, ^{238}Pu is a potential environmental hazard. In the past, the use of ^{238}Pu has generated much controversy and turmoil. Its use in future missions is doubtful because of environmental concerns. This paper presents calculations performed with MCNP for a power source that will take advantage of the low temperatures found in deep space.

Description of the Power Source

Highly enriched uranium is an extremely safe material when compared to ^{238}Pu. The specific activity of ^{235}U is several orders of magnitude less than that of ^{238}Pu.[1] The concept for the new power source is based on the fact that the fission process is increasingly enhanced when neutrons with average energies of 0.001 eV (cold neutrons) interact with fissile material (^{235}U, ^{239}Pu, ^{233}U). For instance, the fission cross section for ^{235}U, which is the probability that a neutron at a particular energy will cause a fission event, increases from 580 barns at room temperature to 3000 barns at energies of 0.001

eV (4 Kelvin). For ^{239}Pu, the fission cross-section increases from **740** barns at thermal energies to 3200 barns at neutron energies of 0.001 eV. It is important to point out that the cross-section of any material depends on the energy of the neutron and on the temperature of the material; particularly, when the neutron energy is in the so-called thermal energy range where the speed of the neutron is comparable to the thermal motion of the molecules or nuclei comprising the medium. In addition, at very low energies, neutrons can behave as waves and interference effects may arise when neutrons are scattered by a crystalline solid medium. This effect is accounted by the $S(\alpha,\beta)$ thermal scattering treatment in the MCNP code. Unfortunately, the $S(\alpha,\beta)$ treatment was not available at the right temperatures (4 Kelvin) for the materials that were used **as** moderators in the models. Another important point is that at low moderator temperatures (4 Kelvin), there is less up-scattering because the moderator molecules vibrate more slowly and more fission are induced.

Computer Model

The MCNP[2] computer transport code was used to model the different configurations. Each configuration consisted of a highly enriched uranium foil approximately 72.3-cm square and 0.00076-cm (0.0003-in) thick surrounded by moderator and reflector. The moderator was heavy water or beryllium or graphite. Its dimensions were 80-cm by 80-cm by 30-cm. The reflector surrounded the moderator and was a 240-cm cube. The reflector was assumed to be of the same material as the moderator. The MCNP code was operated in the KCODE mode and run for 120 cycles, 3000 particles per cycle. The $S(\alpha,\beta)$ thermal scattering treatment was used for those calculations performed at room temperature. No $S(\alpha,\beta)$ treatment was available at cryogenic temperatures; nonetheless, the free gas thermal treatment was used to account for the thermal motion of the atoms when neutrons interact with the moderating and reflecting media. Doppler broadening was done in the processing of the cross section libraries.

Results

Table I shows the results obtained with MCNP. **As** seen in this table, heavy water is the best moderating material due to its low absorption cross section. Consequently, more neutrons interact with the fissile material producing more fissions. When the temperature of the moderator is at 4 K, the thermal flux peak shifts to a lower energy as seen in Fig. 1. Note that the number of cold neutrons is smaller because some of them have been absorbed in the moderator due to the $1/v$ behavior of the absorption cross section for heavy water. **As** seen in table I, the neutron lifetime for heavy water systems is larger when compared with the other systems. This again is an indication of the low-neutron absorption occurring in heavy water. Finally, because of the small mean free path for cold neutrons in uranium, the uranium foil in the system must be very thin to reduce the self-shielding effect of the fuel. Similar calculations have been performed by Olson[3] and Yates[4] and have produce similar results. Experiment must be performed to confirm that indeed small critical masses can be attained when cold neutrons interact with fissile material.

Table I. Results from MCNP

Materials	Temperature	Uranium Mass	Keff	Neutron lifetime
$D_2$0 Moderator $D_2$0 Reflector	4 K 300 K	72.9 g	1.003097 ± 0.00184	7.46E-3 sec
$D_2$0 Moderator $D_2$0 Reflector	300 K 300 K	72.9 g	0.322410 ± 0.00081	4.49E-3 sec
Be Moderator Be Reflector	4 K 300 K	72.9 g	0.400340 ± 0.00112	2.23E-3 sec
Be Moderator Be Reflector	300 K 300 K	72.9 g	0.291240 ± 0.00069	1.58E-3 sec
C Moderator C Reflector	4 K 300 K	72.9 g	0.299780 ± 0.00101	4.22E-3 sec
C Moderator C Reflector	300 K 300 K	72.9 g	0.170550 ± 0.00066	3.62E-3 sec

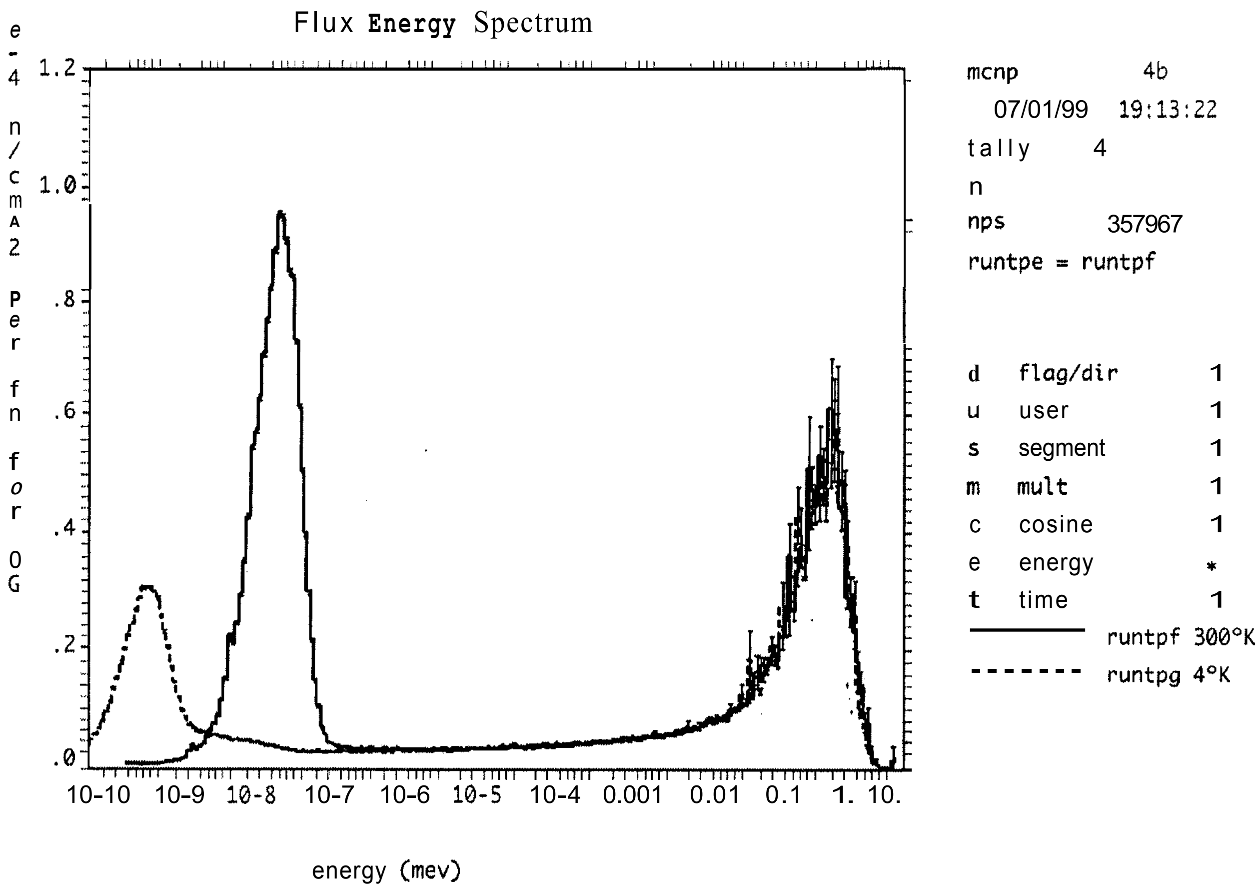

Figure 1. Neutron Flux calculated by MCNP in the center region of the configuration for the heavy water moderated and reflected system.

References

1. John W. Healy, Los Alamos Handbook of Radiation Monitoring, LA-4400, Los Alamos National Laboratory (1970).
2. J. F. Briesmeister, "MCNP – A General Monte Carlo N-Particle Transport Code," Los Alamos National Laboratory report LA-12625-M, Version 4C.
3. R. S. Olson and M. A. Robkin, "A New Small Mass Critical Configuration," Transactions American Nuclear Society, 13, 669 (1970).
4. K. R. Yates, "Criticality of Thin Flat Foils Versus Spherical Shells of ^{239}Pu," Transactions American Nuclear Society, 27,415 (1977).