Letters to the Editor

Comments on "The Nonlinear Dynamics of the Oklo Natural Reactor"

The conclusions in the paper by Bilanovic and Harms[1] concerning the supposedly chaotic dynamics of the Oklo phenomenon[2,3] should be reevaluated.

The authors base their simulation results on the behavior of a dynamic model of a boiling water reactor[4] (BWR). In particular, they use a predicted period of a BWR limit cycle (2.3 to 2.5 s) to infer parameters for their model of Oklo. It would appear, however, that the reactivity feedback mechanism in Oklo has very little in common with any simulation model of a BWR.

If the authors had constructed a hydrogeologic feedback model with reasonable parameters, and then demonstrated period-doubling bifurcations on the computer, they would have had an exciting result. Without that, their conclusions should be regarded as speculative.

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2. "Le Phenomene d'Oklo," *Proc. IAEA Int. Symp. Oklo Phenomenon*, Libreville, Gabon, June 23-27, 1975, CONF-750641, International Atomic Energy Agency (1975).

3. G. A. COWAN, *Sci. Am.*, **235**, *1*, 36 (July 1976).

4. J. MARCH-LEUBA, D. G. CACUCI, and R. B. PEREZ, *Nucl. Sci. Eng.*, **86**, 401 (1984).

Response to "Comments on 'The Nonlinear Dynamics of the Oklo Natural Reactor'"

We welcome David Hetrick's letter[1] and offer the following comments:

1. As we indicated,[2] the period 2.3 to 2.6 s was chosen because this yielded the burn duration of $\sim 10^6$ yr as estimated for Oklo by other methods (p. 291).

2. Our view of the commonality of the feedback mechanism between Oklo and a boiling water reactor extends only to the recognition that with increasing temperature, water will boil.

3. We share Hetrick's interest in a realistic hydrogeologic model of the Oklo environment but wonder how this can be achieved about an event that occurred ~2 billion yr ago and lasted about a million years.

4. Finally, Hetrick may be reading more into our conclusion than intended. In our closing paragraph we state that "... it *may have been possible* for the Oklo reactor, and other natural reactors, to operate in a totally random or chaotic fashion."

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2. Z. BILANOVIC and A. A. HARMS, *Nucl. Sci. Eng.*, **91**, 286 (1985).

Comments on "Application of Neutron Transport Green's Functions to the Calculation of Pressure Vessel Fluence"

Carew et al.[1] have recently derived a simple and accurate analytic method for calculating pressure vessel neutron damage >1-MeV fluence. The method employs a one-speed neutron transport Green's function, together with an effective removal cross section obtained by fitting transport flux results. The analytic method reproduces detailed two-dimensional numerical flux results within 5%.

The use of a Green's function or point kernel in such an application was reported earlier.[2-4] An irradiation exposure profile was calculated[2] for the reactor pressure vessel of the Portable Medium Power Plant (PM2A) and was compared with experimental measurements. Calculated values of ^{54}Mn activity and of exposure (time-integrated neutron flux >1 MeV) were given at three radial locations through the vessel wall at the maximum axial-azimuthal location. Comparisons of calculated and measured ^{54}Mn activity at the inner edge of the vessel were given azimuthally at three axial locations. For the 25 data points taken at the core centerplane, where the exposure was a maximum, the average calculated-to-measured activity was 1.05, with an average deviation of 0.07. The agreement was within the uncertainties of the calculated or experimental results.

In these earlier calculations, the neutron flux spectrum was obtained from the core centerline to beyond the pressure vessel by means of a one-dimensional, multigroup P_3 transport program. Geometrical correction factors were applied to the flux results to account for the finite height of the core, for the azimuthally averaged source variation in the radial and axial directions within the core, and for the array of square modules of the core and the attendant fission neutron source variation within them. These correction factors were obtained from integration over the reactor core volume of a point kernel for a fission neutron source in water, which was a measure of the fast neutron attenuation in water. In particular, the SPIC-01 option of the SPAN-3 point-kernel integration program[3] was used since this option employed a kernel for fast neutron dose rate in water generated from moments method spectral flux results.

Even earlier, experimental information had also been presented that substantiated the use of several point attenuation kernels and their exponential representation for neutrons in water.[4] The point kernel for fast neutron dose rate in water is

$$\frac{4\pi r^2 D(r)}{s} = 0.0316\exp(-0.098\rho r) + 0.221\exp(-0.160\rho r) - 0.1275\exp(-0.283\rho r) \;,$$

where

s = source strength (fission neutron/s)

r = distance in water from the source (cm)

ρ = specific gravity of the water

D = biological neutron dose rate (mrem/h).

This representation is valid out to 120 cm of water and is presumed valid beyond 120 cm. It is interesting to note that the asymptotic effective removal cross section for water in this kernel ($0.098\ \text{cm}^{-1}$) is not very different than the values for an iron/water array ($0.1135\ \text{cm}^{-1}$) and for water ($0.11\ \text{cm}^{-1}$) cited by Carew et al.[1]

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