THE OKLO NATURAL URANIUM REACTOR: EVIDENCE FOR A YOUNG EARTH

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Abstract

A fossil nuclear reactor is believed to have been discovered at Oklo in Gabon, Africa. The author has previously considered the scientific data from the viewpoint of a creationist. In this work further studies of concentrations of uranium and of reactor by-products are presented and discussed as they relate to determining the age of the reactor. The data still seem to be consistent with the young earth view.

Introduction

In an earlier article,[1] hereafter referred to as A, data from the Oklo natural fission reactor in Gabon, Africa were examined to demonstrate their consistency with the young earth model of creationists. To review briefly the history involved, it was discovered by some French scientists in 1972 that a body of uranium ore at Oklo in Gabon contained several zones which had once been natural reactors. Subsequent researchers concluded that the self-sustaining nuclear reactions must have occurred about 1.9 billion years ago.[2,3] In A, the author considered various aspects of the available data, including the relationship between neodymium (Nd) isotope concentrations and uranium (U) fuel depletion as well as the effective multiplication factor (k_{eff}) for the neutron population. It was concluded that the data were consistent with an interpretation in terms of an earth as young as 6000 years or so. One of the crucial arguments involved the diffusion of the isotopes of neodymium. It was crucial since a self consistent model of the Oklo phenomena must match the production rates of fission products and the duration and age of the reactors with the observed amounts of fission products which have survived at Oklo. In this article the mechanism of neodymium diffusion will be discussed, the evidence provided by some other fission products will be considered, a more detailed consideration of the fast fission factor involved in the calculation of the effective multiplication factor will be given, and a possible alternative model involving variable decay constants will be introduced. This alternative model also seems to be able to explain the data from Oklo in terms of a young earth, and the author has not come to any definite conclusions as to which model is better.

Neodymium Isotope Concentration and Fuel Depletion

In A, data were considered which gave the concentrations of the various stable isotopes of the rare earth element neodymium (Nd) as a function of position through the reactor zones. Neodymium has seven stable isotopes: Nd-142, Nd-143, Nd-144, Nd-145, Nd-146, Nd-148, and Nd-150; and only one of them, Nd-142, is not formed as a result of fission.[4-6] Cowan et al.[7] used the Nd-142 concentrations as a means of determining the amount of the neodymium already present at the various positions in the reactor zone, before the Oklo fission reactions took place (the "primordial" neodymium). In A, it was pointed out that Cowan et al.'s arguments for a 1.9 billion year age for the reactor were invalidated, if the Nd-142 isotope concentration had changed due to Nd-142 diffusion. A graph was shown of Nd-142 concentration versus position, which gave strong evidence for Nd-142 diffusion, and hence showed that other age estimates of the Oklo ore may be supported by the data, including ages as small as 6000 years or so. The young earth interpretation is only possible, however, within this framework of assumptions, if Nd-142 diffuses at a faster rate than the other neodymium isotopes. In this article possible mechanisms of diffusion will be discussed, and evidence presented which shows that Nd-142 should definitely diffuse at a different rate than the other Nd isotopes.

Neodymium is normally 27.2 percent Nd-142, while the percentages of Nd-143, Nd-144, Nd-145, Nd-146, Nd-148, and Nd-150 are 12.2, 23.9, 8.3, 17.2, 5.7, and 5.6, respectively.[8] These are the percentages that have been found in samples containing neodymium and apparently are the same no matter where the sample was collected, although a slight but notable variation has been discovered in the Allende meteorite.[9,10] Cowan et al. used these percentages, plus the measured concentrations of Nd-142, to calculate the presumed amounts of primordial neodymium isotopes present at each position in the reactor zone. These "primordial amounts" were then subtracted from the measured amounts of the various neodymium isotopes at the same positions, to obtain the presumed amounts formed as a result of fission. Cowan et al. compared the results of these calculations to the amounts of fuel depletion, and concluded that the two results did not compare favorably unless the fission reactions occurred about 1.9 billion years ago. U-235 and U-238 have half lives of 704 million and 4.47 billion years,[11] and hence 1.9 billion years ago the percentage of uranium that is U-235 would have been larger. See Figures 1 and 2. This point, according to Cowan et al.'s assumptions, would mean a larger amount of fission would be required to explain present U-235 concentrations if the reactions occurred 1.9 billion years ago as opposed to more recently. The larger amount of fission of U-235 is consistent with the large amount of neodymium which has to be interpreted as fission product neodymium in Cowan et al.'s model.

In order to upset the above arguments, we need only to note the Nd-142 had to diffuse out at a different rate than the other neodymium isotopes. If the neodymium isotopes all diffuse out at the same rate, then

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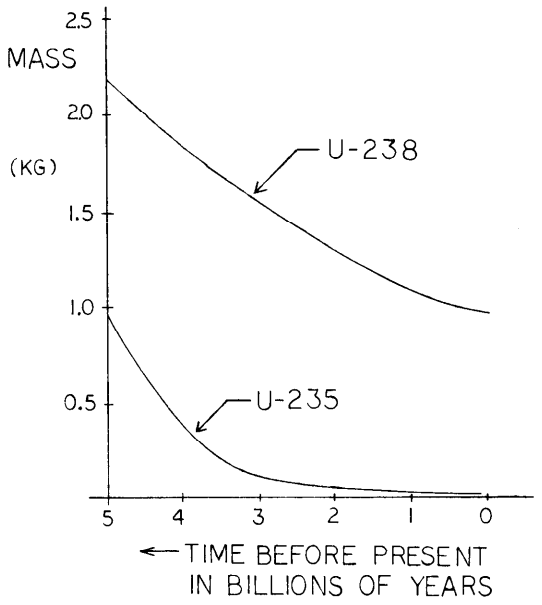

Figure 1. The amounts of U-235 and U-238 that would have been present, at various times in the past, if one kilogram of natural uranium survives at the present epoch, according to extrapolation of the law of radioactive decay. The "conventional" model of the Oklo reactors relies on the increased proportion of the uranium that would have been U-235 a couple of billion years ago in order to explain the Oklo data.

the Nd-142 concentration would give a true measure of the amount of primordial Nd *still present.* The amount of the fission product isotopes Nd-143, Nd-144, etc. still present at a location could be calculated. This amount of presumed fission product neodymium still present is too large to be explained by the young earth model by a factor of about 4.5 to 6.5, according to simple calculations.

However, evidence can be found, and will now be presented, which shows that Nd-142 could have diffused at a larger rate than the other neodymium isotopes. Nd-142 is special compared to the other Nd isotopes in that it has a closed neutron shell nucleus. The neutron number N = 142 - 60 = 82, one of the so-called "magic numbers" in nuclear shell theory.[12] Interestingly, this is related to the diffusion probability through the recoil caused by neutron scattering. Through the recoil probability involved in neutron scattering, if a neutron of sufficient kinetic energy (greater than about 0.7 keV) collides with a neodymium nucleus and scatters, the nucleus will recoil with enough kinetic energy to leave a lattice site or to break a molecular bond.[13]

For elastic scattering, the maximum change in neutron kinetic energy is given by[14]

$$\Delta KE = KE_i \frac{4A}{(A+1)^2} \qquad (1)$$

where A is the mass number of the target nucleus and KE_i is the initial neutron kinetic energy. This kinetic energy lost by the neutron will be gained by the recoiling nucleus during the scattering. Thus if the bond energy is about 20 eV, and A is of the order of 142 to 150, then the initial neutron kinetic energy must be at least about 0.7 keV in order for the nuclear recoil to be enough to knock the nucleus free. If the bond energy is 25 eV (or 5 eV), the required neutron kinetic energy changes, but remains the same order of magnitude as 0.7 keV.

Now the neutron flux per unit energy interval is inversely proportional to the kinetic energy. Hence, although fission neutrons are born at nearly 2.0 MeV of kinetic energy, most of the neutrons which cause neodymium nuclei to be knocked free will have kinetic energies just above 0.7 keV. The values of the scattering cross sections from 0.7 keV to about 30 keV are given in reference 15. Hence, a measure of the relative probability of the various neodymium isotopes being knocked free is given approximately by the integral of this cross section divided by the kinetic energy, from 0.7 keV to 30 keV. A complication is the fact that Nd-143 and Nd-145 have large neutron capture probabilities. Thus comparisons of the present day concentrations with the cross section data need to be done by combining the results for Nd-143 with Nd-144 and the results for Nd-145 with Nd-146. Only these combinations can be considered in a way that is nearly independent of neutron fluence and hence model independent (Neutron fluence is the integral of neutron flux over time). The combination must be performed by using the isotopic percent abundances as well as an estimate of how these will change with time in the reactor. The results, shown in Table I, indicate that Nd-142 should have a smaller probability of being knocked free than any of the other isotopes or isotopic combinations. This might at first seem to imply that Nd-142 should diffuse *less* than the other isotopes, which would be the opposite conclusion to which the creation model has led us. However, a neodymium ion which has been knocked free from its position does not necessarily diffuse out of the reactor zone at a faster rate than the neodymium atoms that have not

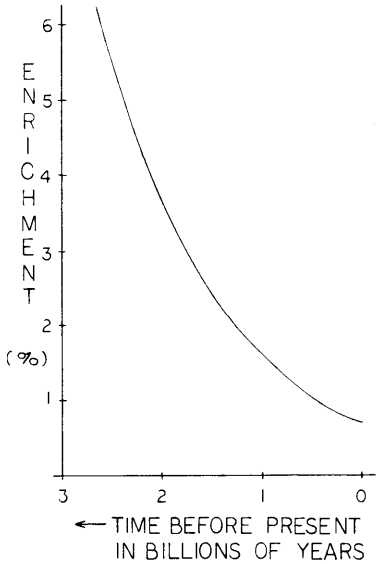

Figure 2. The enrichment, that is, the percentage of the uranium that is U-235, versus time, zero representing the present epoch. The curve is obtained by extrapolating the law of radioactive decay into the past, using the results of Figure 1. About 1.9 billion years ago. the enrichment would have been just over 3 percent. Presently, natural uranium normally has an enrichment of 0.72 percent.

been "knocked free." This also depends on the probable types of chemical recombination in the minerals in the reactor zone, and the diffusion rates (say, by water transport) of these "types."

Now the minerals and rock material found in the Oklo zones included uranite, quartzite, amorphous carbon, pelite, and others.[16] Pelite is a term meaning "mudstone," indicating that clay minerals were present. The 2P'traverse mentioned in reference 3 crosses a 3 cm thick clay filled fault near sample 1182. This fault may have served as a conduit for water percolation. The ability of the diverse array of mineral phases at Oklo to retain neodymium thus seems to be a complex problem. It may be said, however, that mineral phases undoubtedly exist which are better able to retain neodymium than others. By "retain" neodymium we mean to keep it localized in the mineral, resisting any tendency for it to dissolve in any water percolating through the ore. The neodymium could nevertheless be transferred from one mineral to another by recoil following neutron scattering. Thus, when the Oklo chain reactions started, the neutrons produced may have served to knock Nd-143, Nd-144, etc. out of position more often than Nd-142, thus providing a mechanism by which Nd-142 would be left predominantly in a different mineral phase than the other neodymium isotopes. We hypothesize that the mineral phase in which Nd-142 was predominantly found was then more susceptible to water action. Diffusion over long distances then took place by water action, not by recoil following collisions with neutrons.

As an oversimplified example of a set of mineral phases capable of supporting the above diffusion mechanism, consider a solid solution of Nd^{+3} ions in mixed crystals of $U0_2$, UO_3, Ce_2O_3, and CeO_2. By a "solid solution" it is meant that the neodymium ions occasionally replace the uranium and cerium ions in the lattice structure, or are present at interstitial sites. Now the UO_3 and CeO_2 are more water soluble in basic solutions than UO_2 and Ce_2O_3, as explained in references 17 and 18. Hence, under the right conditions the neodymium present in the UO_3 and CeO_2 phases would be more susceptible to water transport than that in the UO_2 and Ce_2O_3. Therefore the nuclear recoil caused by neutron scattering could be responsible for a higher isotopic percentage of Nd-142 being present in one phase than in the other, and hence in Nd-142 diffusing more than the other neodymium isotopes.

In this connection, it might be mentioned that a similar recoil mechanism was resorted to by Lugmair et al.,[19] and further studied by Clayton[20] and Kappeler et al.[21] to explain the anomalous Nd-143 concentrations found in the acid insoluble residues from the Allende meteorite. In this case, the recoil was that following the alpha decay of Sm-147.

Nd-142 has a lesser "knockout" probability than any of the other neodymium isotopes or isotopic combinations (see Table I). If it had an intermediate value, the model presently being considered would be implausible. But the lesser value for Nd-142 lends credence to our model, which can be strengthened by the following numerical arguments (see column 3 of Table I).

Table I. A Measure of the "Knockout" Probability for ND Isotopes or Isotopic Combinations and Corresponding Fractions which Diffused Outward.

Isotope or Isotopic Combination	$\int_{.7\,keV}^{30\,keV} \sigma_5(E)\frac{dE}{E}$ (barns)	Fraction Which Diffused Out
Nd - 142	17.0	$r' = 0.67$
Nd - 150	20.4	$.453 < r < .459$
Nd - 148	29.7	$.15 < r < .16$
Nd - 145 & Nd - 146	28.8	$.19 < r < .20$
Nd - 143 & Nd - 144	39.6	$.11 < r < .12$

We consider the total concentrations of the isotopic combinations Nd-143 plus Nd-144, Nd-145 plus Nd-146, Nd-148 alone, and Nd-150 alone for each position in the reactor zone, and define for each the following:

x = the initial concentration before any fission took place,

r = the fraction of the initial concentration x that has been lost by diffusion,

s = the fraction of the isotopic combination produced from fission that was subsequently lost by diffusion.

We also define:

r' = the fraction of the original Nd-142 concentration that has been lost by diffusion.

Next, knowing the percent abundances of the different neodymium isotopes, we hypothesize that:

i) The initial Nd-142 concentration may be found by multiplying the value of x by the appropriate ratio of percent abundances. For example, when x represents the isotopic combination Nd-143 plus Nd-144, then the initial Nd-142 concentration is:

$$\frac{27.1}{36.1}x \qquad (2)$$

since the percent abundances of Nd-142, Nd-143, and Nd-144 are 27.1 12.2, and 23.9 percent respectively, and 12.2 + 23.9 = 36.1 percent.

ii) The final Nd-142 concentration may be found by multiplying the result of i) by (1 - r). The quantity 1 - r'would be of course the fraction of the original Nd-142 concentration that has *not* been lost by diffusion. For example, when x represents the isotopic combination Nd-143 plus Nd-144, then the final Nd-142 concentration is:

$$(1 - r')\frac{27.1}{36.1}x\,. \qquad (3)$$

These two hypotheses, plus the above definitions are enough to place bounds on the possible values of x, r, s, and r'. For example, the final concentration of Nd-143 plus Nd-144 must be:

$$(1 - r)x + (1 - s)(\gamma^{143} + \gamma^{144})\frac{\sigma_f^{25}}{\sigma_a^{25}}(N_i^{25} - N_f^{25}). \qquad (4)$$

Here γ^{143} and γ^{144} are the fission yield coefficients of Nd-143 and Nd-144 (see reference 22), σ_f^{25} and σ_a^{25} are the respective fission and absorption cross sections of U-235, and N_i^{25} N_f^{25} are the initial and final U-235 concentrations.

By considering equations (3) and (4) simultaneously and using the data for sample point 1402/2 given by Cowan et al.,[23] it is easy to show that the fraction r' must be between 0.626 and 1.0 if s is indeed a fraction (between 0 and 1). Taking arbitrarily the sample value r'= 2/3, we then find the value of r (the fraction of the original concentration that has been lost by diffusion) to be as given in the third column of Table I. Since the fraction of Nd-142 lost by diffusion, r,' is bigger than any of the allowed values of r, and furthermore there seems to be a correlation between columns 2 and 3 of Table I, these numerical studies show that the amount of diffusion that must have occurred for each isotopic combination was determined by the "knock-out" probability caused by neutron scatterings.

To conclude, numerical studies, summarized here, give strong evidence that Nd-142 diffused out of the reactor zones at Oklo at a rate faster than the other neodymium isotopes. This in turn enables the Oklo data involving neodymium and uranium concentrations to be explained in terms of a young-earth model.

If experimental determinations of the diffusion rates of neodymium could be done, it might be possible to rule out the conventional 1.9 billion year old view of the reactor. The experiment might involve placing samples of Oklo minerals inside a cavity in a reactor, while simultaneously subjecting the sample to a flow of water over its surface. Ion microprobe and other techniques, used before and after the reactor exposure, could then reveal the extent to which Nd-142 concentration changed as compared to other neodymium isotopes. Since the author is a theoretician, this is offered as a suggestion for those with expertise in this type of experiment.

It should be mentioned that ion microprobe studies, notably those of Havette,[24] give data on the change in concentration of various products with position in the grains of ore. Some have concluded on the basis of these data that the neodymium fission products essentially stay in place with the uranium.[25,26] However, the loss of a finite fraction of the *primordial* neodymium is also consistent with these data. The ion microprobe data imply that s is near zero but make no claim about r and r,' where s, r, and r' are the quantities defined in this paper. In other words, we are claiming that the predominate primordial chemical species containing neodymium were apt to allow neodymium migration, whereas the forms of neodymium produced from fission were not as apt to migrate. Also, the smaller neutron scattering cross section of Nd-142 would mean that it would tend to remain in the primordial chemical combination, and hence not recombine with the less mobile chemical species. Hence Nd-142 would diffuse out at a faster rate.

As corroborative evidence, it might be mentioned that Cowan et al.'s[27] data for SC-23, a sample taken two meters from reactor zone one, has 27.35 percent Nd-142, whereas natural neodymium is supposed to be only 27.11 percent Nd-142. This is exactly what our model would predict. Also, Maeck et al.[28] state: ". . . U and Nd data from the SC-36 core samples at the edge of the rich U lens are highly discordant and indicate fission product and/or U redistribution."

Consideration of Other Reactor By-products

Besides neodymium, other fission products such as rubidium, strontium, xenon, and samarium could be studied. The author will discuss some of the results involving these other fission products as well as the reactor by-product Pu-239.

Lancelot et a1.[29] and Hageman et al.[30] studied Rb-85, Rb-87, Sr-86, Sr-87, and Sr-88. Rb-85, Rb-87 and Sr-88 are fission products while Sr-86 and Sr-87 are not. Also, none of these five isotopes has an appreciable neutron capture cross section. Rb-87 is radioactive with a half life of 5.2×10^{10} years, decaying into Sr-87. It should be possible to distinguish between the young earth and conventional models using data on these isotopes. However, the experiments show that only traces of fission product Rb-85, Rb-87, and Sr-88 are present, and it is concluded that they must have leached out. Less of these products would have been produced if the young earth model is correct, but in either model the amount that should have been present, if no leaching had occurred, is more than the actual traces detected. We can gauge the amount of primordial strontium and rubidium by calculating ratios of the measured concentrations and comparing with ratios based on the known percent abundances of the different isotopes and also the known fission yields. The result is that almost zero percent is due to fission, i.e., only traces are "detected." Hence we conclude that, since Rb and Sr are water soluble, the fission product Rb and Sr were produced in a form that was leached away by ground water, whereas the Rb and Sr that were "primordial" were present in mineral combinations that were not so water soluble. Hence primordial Rb and Sr remain but very little, if any, of the fission product Rb and Sr are present.

Thus the rubidium and strontium data are inadequate to decide between the young earth model and the conventional model.

Xe-135 and Sm-149 are important fission product poisons. They will be produced as a result of fission, and have large neutron capture cross sections. Thus, after a reactor has been operating long enough, their concentrations build up to a point where there will be many neutrons captured, and these neutrons will not be able to cause fission, hence the name "poisons." If the young earth model is correct, the Oklo reactor would only just be able to maintain a self sustaining reaction. The buildup of Xe-135 and Sm-149 might thus cause the reactor to shut down. However, Xe-135 is radioactive with a half life of 9.2 hours, and it decays into an isotope which does not have an appreciable neutron capture probability. Hence, even if Xe-135 poisoning were a problem, the Oklo reactor could have operated in spurts, with a matter of hours between these "spurts." The Sm-149, on the other hand, is not radioactive and would remain even if the reactor shut down. However, the maximum reactivity contributed is only about 0.04, since of course Sm-149 is removed by neutron capture during reactor operation.[31] Thus Xe-135 and Sm-149 do not present a serious threat to the young earth model.

Pu-239 is bred" in nuclear reactors as a result of neutron capture by U-238, followed by two beta-minus decays. Walton and Cowan[32] quoted ionic probe analyses as evidence that U-235 and U-238 occur in exactly the same positions. They concluded: "This would not be the case if Pu-239, during its half life of 24,400 years, had moved more than a few microns." This conclusion rests on the fact Pu-239 decays by alpha emission, becoming U-235. In the conventional model, with its longer duration of the reactions than the young earth model, large amounts of Pu-239 would have been bred and subsequently decayed into U-235 during the 1.9 billion years. Hence, if Pu-239 had migrated more than a few microns, Walton and Cowan claim that anomalies would be noted in the percentage of uranium that is U-235. Now the percentage of uranium ore that is U-235 is less than normal in the reactor zones, and this is one reason why we know a nuclear reactor existed. However, if Pu-239 had migrated, samples near the edge of the zone (or possibly even near the edges of mineral grains) might show anomalously high percentages of U-235.

Now in the present young earth model, very little decay of Pu-239 could have occurred in the approximately 6000 year history of the earth, and we are free to conclude that there may have been more migration of plutonium and uranium than Walton and Cowan must conclude in their model. It would be interesting, therefore to have data on plutonium concentrations in and near the Oklo reactor zones. Pu-239 is occasionally detected in trace amounts on earth, and are usually blamed on chance neutron irradiations rather than natural reactors.

The possibility of uranium migration no doubt also plays a role in explaining the Oklo data. Maeck et al.[33] stated: "Some redistribution and possibly migration of U may have occurred, especially at the edges of the ore zone." They go on to state that assuming water transport is not unreasonable. In the *Cambridge Encyclopedia of Earth Sciences*[34] we find the statement: "Extremely mobile elements such as uranium have often been leached away from rocks which appear fresh and unaltered." Also, it states:

> . . . although uranium is extremely mobile under oxidizing conditions, it quickly becomes insoluble and drops out of solution when conditions become more reducing.

I conclude that studies of the variation of plutonium and uranium concentration do not disprove the young earth model.

The Fast Fission Factor and the Neutron Population

In A, it was argued that the Oklo reactor could have maintained a self sustaining nuclear reaction even if the ore had an enrichment of only 0.72 percent. This enrichment is the value to be expected on the basis of the young earth model, A weak point in the argument was the statement that the fast fission factor, ϵ, could have been as much as 1.2. Some who are accustomed to working with nuclear power reactors where ϵ is closer to 1.0 may doubt the validity of this value. The author would like to give a theoretical treatment of this matter showing that 1.2 is not an unreasonable value of ϵ for the Oklo reactors.

We begin by defining the fast fission factor as the number of neutrons produced by all fissions divided by the number of neutrons produced by thermal fissions. It is then given by:

$$\epsilon = \frac{\nu_2\int_0^{E_{th}} N^{25}\sigma_f^{25}\phi(E)dE + \nu_1\int_{E_{th}}^{\infty} N^{25}\sigma_f^{25}\phi(E)dE + \nu_0\int_{E_{th}}^{\infty} N^{28}\sigma_f^{28}\phi(E)dE}{\nu_2\int_0^{E_{th}} N^{25}\sigma_f^{25}\phi(E)dE} \quad (5)$$

where:

- ϵ = fast fission factor
- ν_2 = number of neutrons produced in an average thermal fission of U-235
- ν_1 = number of neutrons produced in an average non-thermal fission of U-235
- ν_0 = number of neutrons produced in an average fission of U-238
- N^{25} = number of U-235 atoms per unit volume
- σ_f^{25} = microscopic fission cross section of U-235
- $\phi(E)$ = average neutron flux per unit energy interval
- N^{28} = number of U-238 atoms per unit volume
- σ_f^{28} = microscopic fission cross section of U-238
- E_{th} = the break between "thermal" neutron energies and non-thermal energies.

In the approximation of infinite dilution of the uranium fuel in the moderator this becomes:

$$\epsilon = 1 + \epsilon\frac{\nu_1 N^{25}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\infty}\sigma_f^{25}\frac{dE}{E} + \epsilon\frac{\nu_0 N^{28}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\infty}\sigma_f^{28}\frac{dE}{E} \quad (6)$$

where:

- ξ = logarithmic energy decrement
- N^{MOD} = number of water (moderator) molecules per unit volume
- σ_s^{MOD} = microscopic scattering cross section in water.

Solving for ϵ, this gives:

$$\epsilon = \frac{1}{1 - \frac{\nu_1 N^{25}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\infty}\sigma_f^{25}\frac{dE}{E} - \frac{\nu_0 N^{28}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\infty}\sigma_f^{28}\frac{dE}{E}} \quad (7)$$

To derive this, I have assumed that the neutron flux per unit energy interval $\phi(E)$ is proportional to $1/E$. Now, above one Mev, this is not a good approximation because E is then near the source energy E_0. A treatment by Placzek[35] divides the considerations into neutrons below αE_o and neutrons above αE_o, where

$$\alpha = \left(\frac{A-1}{A+1}\right)^2 \quad (8)$$

For U-238, the mass number A is 238, and α is near 1.0. Below αE_o it is a good approximation to put $\phi(E)$ as being proportional to $1/E$, while above αE_o it is not. With these modifications, the equation for the fast fission factor becomes:

$$\epsilon = \frac{1}{1 - \frac{\nu_1 N^{25}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\infty}\sigma_f\frac{dE}{E} - \frac{\nu_0 N^{28}}{\xi N^{MOD}\sigma_s^{MOD}}\int_{E_{th}}^{\alpha E_0}\sigma_f^{28}\frac{dE}{E} - \frac{\nu_0 N^{28}\sigma_f^{28}(E_0)}{N^{MOD}\sigma_s^{MOD}(E_0)}} \quad (9)$$

As an example, using this equation, and assuming 10 percent water and 56 percent uranium by weight, the fast fission factor comes out as $\epsilon = 1.16$. Thus the assumption of paper A that $\epsilon = 1.2$ was reasonable. To check whether the use of equation (9) is a reliable model, one might evaluate it for the case of a natural uranium, graphite moderated reactor. In that case the ratio of moderator concentration to uranium concentration is much larger. Weinberg and Wigner[36] give it as 452 as opposed to a value of about 2.4 for the Oklo reactors. The above equation then results in a fast fission factor of about 1.02 for the graphite case, in agreement with experimental results for graphite reactors. Thus this equation seems to be reliable, and since it gives a fast fission factor of 1.16 for conditions simulating the Oklo reactor zones, the assumptions of paper A are vindicated. Thus the young earth model here proposed has satisfactorily explained all the data, thus far.

Variable Decay Constant Models

As was recently pointed out by Morton, Slusher, Bartman, and Barnes,[37] models which allow radioactive decay constants to increase indefinitely as we approach creation have a problem i.e., the large decay rates would have produced too much heat, ultimately enough heat to vaporize the earth. Hence, a more reasonable variable decay "constant" model might be as shown in Figure 3. I suppose that the decay constant, λ, rose to a large value at a time, t_1, perhaps when the Flood occurred, and then it decreased rapidly to its current value.

Gentry[38] has pointed out that for alpha decay, if the kinetic energies, E, of the emitted alpha particles are constant, whereas the nuclear radius, R, does change, then there could be a change in the decay constant, λ, without a change in radioactive halo radii. A model consistent with these conditions might be a model in which there was a variation in the k of Coulomb's law.[39]

How do these models relate to the Oklo reactors? One possibility is that they might allow a recent creation interpretation of the Oklo data even if experimental study of neodymium diffusion shows that it does not occur as the author has proposed in this paper. Alternatively, it may be that a combination of these effects gives a better explanation of the numerical data at Oklo.

In particular, if the Coulomb force were stronger in the past than now, and the nuclear force remained the same, then the fission mass yield curve would shift.[40] The increase in Coulomb repulsion during the rise in decay constant episode would mean an increased production of nuclei with mass numbers just above A = 140. This would mean an increased production of the neodymium isotopes A = 143 to 150. This increased production might make explanation of the Oklo data possible even without resorting to neodymium diffusion.

Summary

It is possible to explain the Oklo reactor as a recent phenomenon, having occurred only several thousand years ago. The study of the properties of the neodymium isotopes shows that Nd-142 has a smaller probability of being knocked out of position by a neutron scattering. This means that the other neodymium isotopes would have a larger probability of recombination into less mobile forms. Hence diffusion of Nd-142 at a faster rate seems possible, and the confirmation of this by experimental study is encouraged. This would show that the Oklo data could be interpreted as a recent phenomenon. The study of rubidium, strontium, xenon, samarium, plutonium, uranium, and other fission related substances at Oklo does not present any significant difficulties for the recent creation model. The study of neutron multiplication also indicates that the Oklo reactions could have occurred in recent times. A possible alternative explanation in terms of an episodic increase in radioactive decay constant was also considered, and seems to be a viable model, at least as far as the investigation has proceeded.

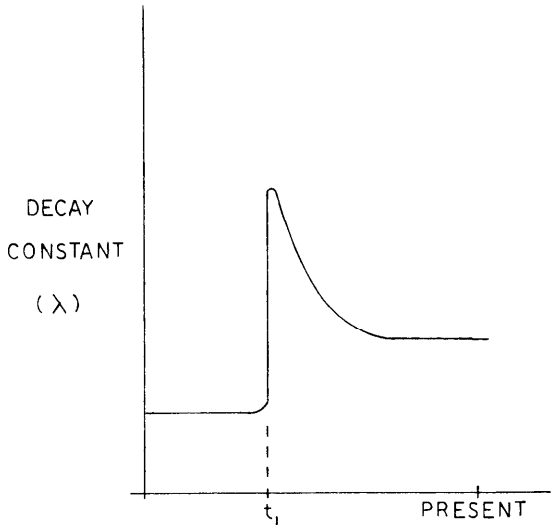

Figure 3. A hypothetical decay constant "episode.' No scale is placed on the vertical axis since the scale would be different for each radioactive nuclide. The time t_1 could possibly be the time of the Flood. In order to possibly explain the polonium halos of Gentry,[38] the decay constant is shown as a smaller value before t_1 than after t_1.

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EXPERIMENTAL RESULTS OF CROWDING ON THE RATE OF ASEXUAL REPRODUCTION OF THE PLANARIAN DUGESIA DOROTOCEPHALA

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Abstract

Natural selection is central to evolution and is thought to provide the mechanism for the development of new species. Pressure exerted by natural selection is thought to play a major role in the regulation of animal populations. If it could be demonstrated that natural selection is not needed for the maintenance of populations or that the harvest of prey species by predators is random, then evolution would be without a mechanism. Experimental evidence is presented indicating the freshwater planarian, Dugesia dorotocephala, *regulates its own population density at healthy levels without need for starvation, disease or predation. Data also indicate worm density is a more important determining factor of reproduction rate than food under certain conditions. Additional work is needed with other species and under natural conditions.*

Introduction

If the Creation/evolution controversy is ever to be resolved, I believe it will be done at the level of population ecology. Fossil evidence from Darwinś time to the present day overwhelmingly supports the Creation model and has little correlation with evolution, but most life scientists ignore the fossil evidence. Philosophical arguments are interesting, but offer no testable data or predictions. Few areas in science have expanded as rapidly in recent years as population ecology and evolution is central to the discipline. Indeed population ecology might be more appropriately called applied evolution. In spite of the upsurge in interest and federal support, the most basic of all population ecology questions remains unanswered: that of how the population of animals in the natural environment is regulated.

Darwin and others rightly observed that, without human intervention or environmental catastrophe, the population density of most animal species remains nearly constant from year to year. This is amazing when one considers annual differences in rainfall, growing season, temperature, wind and other environmental factors. Population stability is also striking when one considers the reproductive ability of most organisms. Darwin was impressed with the reproductive potential of animals which is seldom achieved under natural conditions; certainly not for long. It is this very point that gave Darwin the mechanism for evolution. He assumed animals reproduce at their maximum physiological potential and these excess ani-

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