[11]Bouw, G.D., 1977. Galaxy clusters and the mass anomaly. *Creation Research Society Quarterly* 14(2):108-112.
[12]Bouw, G.D., 1977. The rotation-curve of the Virgo cluster of galaxies. *Creation Research Society Quarterly* 14(1):17-24. Dr. Bouw now has evidence for rotation in the massive Coma Cluster of galaxies.
[13]Hanes, D.A., 1979. A new determination of the Hubble constant. *Monthly Notices of the Royal Astronomical Society* 188(3):901-909.
[14]Hoyle, F., 1975. Astronomy and cosmology. San Francisco, W. H. Freeman and Co., pp. 574-577.
[15]Browne, J.C., and B.L. Berman, 1976. Neutron-capture cross sections for $^{186}O_s$ and ^{187}Os and the age of the universe. *Nature* 262(5565):197-199.
[16]Akridge. G.R., 1979. The expansion of the universe: a study of the initial conditions. *Creation Research Society Quarterly* 16(3):176-181.
[17]Varshni, Y.P., 1976. The red shift hypothesis for quasars: is the Earth the center of the universe? *Astrophysics and Space Science* 43(1):3-8.
[18]*Ibid.*, p. 8.
[19]*Ibid.*, p. 4. Varshni's figure of 3×10^{-85} for the probability is in error and should be 3×10^{-87}.
[20]Burbidge, G., 1971. Was there really a big bang? *Nature* 233(5314):36-40.
[21]Hoyle, F., N.E. Wichramasinghe, and N.C. Reddish, 1968. Solid hydrogen and the microwave background. *Nature* 218(5147): 1124-1126.
[22]Clayton, D.D., 1969. The origin of the elements. *Physics Today* 22(5):28-36.
[23]Hoyle, F., 1975. *Op. cit.*, pp. 401-402.
[24]Roxburgh, I. W., 1977. (In) The encyclopedia of ignorance, R. Duncan and M. Weston-Smith, eds., New York, Pergamon Press, p. 39.
[25]According to current theory masses over about 60 solar masses up to 5.4×10^5 solar masses and then those over about 7.5×10^5 suns will all end up as black holes. This theory ignores a well known theoretical "fact", namely, that stars above about 6 solar masses will not contract homologously. Instead, such stars should (ignoring the problem of initiating the collapse in the first place) collapse only up to a certain point beyond which it cannot contract and during which phase material should be falling onto the star which thus gains mass. Eventually the star "explodes" or "burps", losing mass. This burp is followed by a period of material again falling onto the star and the cycle starts all over again. Of all the evolutionary theories, this one is the best that there is to account for the apparent continuity from galaxy nucleus to quasar. From a creationist point of view this has two effects: first, it lessens the energy problem of sustaining quasars for 10^7 years, the new theory making them only a periodic phenomenon and second, it provides creationists with a complete spectrum in one model since the model need not have anything at all to do with time or evolution. Such behaviour on the part of galactic nucleii is independent of whether they have evolved or not. There are problems with the new theory and these problems are the same as face black hole enthusiasts with accreting disk models. There is also some question as to whether or not any material blown away from the supermassive star would collapse back onto its surface in a time scale which is short on a scale of 10^7 years. But most of these are problems for evolutionists. Finally, this theory avoids black holes since it indicates that supermassive stars will not ultimately collapse into a black hole. Black holes would have to come into being in other ways, if they exist at all.

THE OKLO NATURAL URANIUM REACTOR EXAMINED FROM A CREATIONIST'S VIEWPOINT

EUGENE F. CHAFFIN*

Received 27 August, 1981

In 1972 evidence was discovered that a body of uranium ore found at Oklo in Gabon, Africa, had once been a natural reactor. At least six reactor zones existed in the pre-Cambrian rock found at Oklo. Some have believed that the evidence indicates an age of 1.9 billion years for the reactors. In this paper, arguments are presented which show that the data are consistent with a more recent date for the self-sustaining chain reaction which was achieved—a date, in fact, which would be compatible with young-Earth Creationism.

In 1972, while analyzing some uranium which had been mined at Oklo in Gabon, Africa, some scientists working at the nuclear-fuel-processing plant at Pierrelatte in France discovered some ore which had an abnormally small percentage of U-235 as compared to U-238. In most ore the fraction of the total uranium which is U-235, called the enrichment, is 0.72%. No natural uranium had ever been previously discovered which was more than ±0.1% different from 0.72%. In trying to explain why the particular ore being analyzed was different, it was found that a fission chain reaction had occurred in this ore, hence a natural reactor had existed (probably started by an influx of water to serve as a moderator) long before man ever discovered fission or built a nuclear reactor. The various arguments involved have been discussed by Cowan.[1,2] It also seems to have been concluded that the data are not consistent with an age for the reactor less than about 1.9×10^9 years. The author does not agree that this conclusion is necessary, and in this paper would like to present arguments to show that a younger age can be supported by the data, in fact an age as recent as 6000 years or so. There are four areas which need to be discussed: I. Interpretation of the Reactor as it Relates to the Genesis Flood, II. Nd-142 Concentration and Fuel Depletion, III. The Total Number of Megawatt-Hours of Energy Produced by the Reactor, and IV. The Effective Multiplication Factor for the Neutron Population.

I. Interpretation of the Reactor as it Relates to the Genesis Flood

In historical geology, it has become common practice to relate different strata found at a location to a "geological time table" spanning a few billion years. Creationists do not deny that the different strata exist, but interpret them in terms of different types of sediment deposited by the Genesis flood.[3] In the Oklo area of Africa, the surface rocks are pre-Cambrian rocks, which according to standard historical geology are the oldest and lowest lying strata. According to our young earth model, the pre-Cambrian rocks would either be the lowest lying sediments from the flood, or else the pre-flood rocks.

*Eugene F. Chaffin, Ph.D. is at Bluefield College, Bluefield, Virginia 24605.

II. Nd-142 Concentration and Fuel Depletion

One result of any fission chain reaction is a production of fission fragments. Any viable theory of the Oklo reactor must therefore be able to explain and correlate two sets of data. One is the percentages and amounts of U-235 and U-238 left in the Oklo ore at present. The other is the amounts of different isotopes of the fission product elements remaining in the ore at present. Both of these sets of data, plus a theory, give us estimates of the amount of fission that has occurred, and both sets of data must result in the same estimate if the theory is correct.

There are approximately thirty elements which are produced with reasonable probability as a result of fission.[4,5] Approximately 15 of these elements were found in the Oklo ore, still present and immobilized.[1] The other 15 were probably dissolved and carried away by the water percolating through the ore (This process is called leaching.)

One element which did not leach away and was particularly suitable for numerical studies is the rare earth element neodymium (Nd). It is suitable since it has seven stable isotopes: Nd-142, Nd-143, Nd-144, Nd-145, Nd-146, Nd-148, and Nd-150; and one of them, Nd-142, is not formed as a result of fission.[1,4,5] The fact that Nd-142 is not formed as a result of fission means that we can calculate the background levels of the other six isotopes from: a) the amount of Nd-142 present locally at different points in the reactor zones, and b) the known percentages of neodymium that are the different isotopes of neodymium in natural deposits found elsewhere on earth. This method of calculation involves the assumption that these percentages of neodymium isotopes are the same at different locations and were the same 1.9 billion years ago or 6000 years ago (depending on which model is accepted); but in this paper we will assume that this assumption is correct. We then have a viable method of calculating how much of the different neodymium isotopes were present at the different points in the reactor zones before any fission took place.

From these studies of neodymium we can estimate the number of fissions which must have occurred to produce the neodymium. (Actually, small corrections must be applied to take into account neutron absorptions such as those which change Nd-143 into Nd-144 and Nd-145 into Nd-146.) We can then calculate independently, from the percentage of the uranium left at present as U-235 and the actual concentration of uranium, the amount of uranium that must have fissioned. These two ways of calculating the number of fissions must agree. From initial uranium concentration, N_i^U, final uranium concentration, N_f^U, initial enrichment, E_i, and final enrichment, E_f, one can calculate the number of U-235 atoms depleted as

$$\Delta N^{U-235} = E_f N_f^U - E_i N_i^U \qquad (1)$$

Multiplying by the ratio of microscopic fission cross section to the microscopic absorption cross section then gives the number of fissions, to be compared with the number of fissions calculated on the basis of neodymium concentrations. At this point, one must introduce a theory in order to give values for the intial enrichment, E_i, and initial uranium concentration, N_i^U, since these cannot be measured (They refer to the past, before any available measurements.) In the recent creation model, E_i probably must be 0.72%, although the study of pleochroic haloes indicates that decay constants have been variable[6,7], and hence the enrichment may have been slightly different. However, in this work we will assume that E_i is 0.72%. If the conventional 1.9 billion year age of the reactor were the correct model, then E_i should be about 3% due to the different rates of decay of U-235 and U-238.

In both our recent creation model and the conventional model, the results at first come out wrong, the apparent amount of fission that occurred does not come out equal to the amount that should have occurred to produce the present quantities of neodymium. Part of the discrepancy is due to: 1) fission of Pu-239, 2) decay of Pu-239 to U-235, 3) fast neutron induced fission of U-238, and 4) possible changes in the size and shape of the ore. When these factors are taken into account, those who developed the conventional 1.9 billion years age model concluded that the data are consistent with their model. At first it seems as if our creation model cannot explain the actual data realistically. In fact, Cowan et al.[2] concluded that the data were inconsistent with an age less than about 1.9 billion years. According to their line of reasoning, a recent age for the reactor gives an amount of fission less than the amount that the present concentrations of neodymium in the reactor zones would indicate. However, Figure 1 shows why this conclusion is not correct, according to reasoning that the author would like to propose. In the reactor, the higher temperatures present, plus the increase in defects in solids caused by radiation (which causes a greater probability of diffusion[8]), caused a slow diffusion of atoms outward, and this diffusion would have nearly halted after the reactor shutdown. The graph of Nd-142 concentration (Fig. 1) shows that more Nd-142 is present at the edges of the reactor zone, and the concave upward shape indicates that Nd-142 has had a decrease in concentration in the interior of the reactor. This graph is a plot of data given by Cowan et al.[2] for the 2'P' traverse of one of the reactor zones. Other data give similar results. Recalling that Nd-142 is the isotope not produced as a result of fission, this tells us that more of the neodymium isotopes were present to begin with than assuming a constant-in-time Nd-142 concentration would indicate. Thus fewer fissions were needed to produce the observed amounts of neodymium! It is the author's contention that the recognition of this point brings the data into consistency with the recent creation model for the Oklo reactors!

III. The Total Number of Megawatt-Hours of Energy Produced by the Reactors

The reactors envisioned according to our recent creation model turn out to be a bit different from that of the "conventional" theory. The total energy that the Oklo reactors produced was about 440 Megawatt-years according to our model and 15,000 Megawatt-years in the "conventional" model.[1] By comparison, the now famous Three Mile Island reactor, which was rated at 2772 Megawatts of thermal power, would have produc-

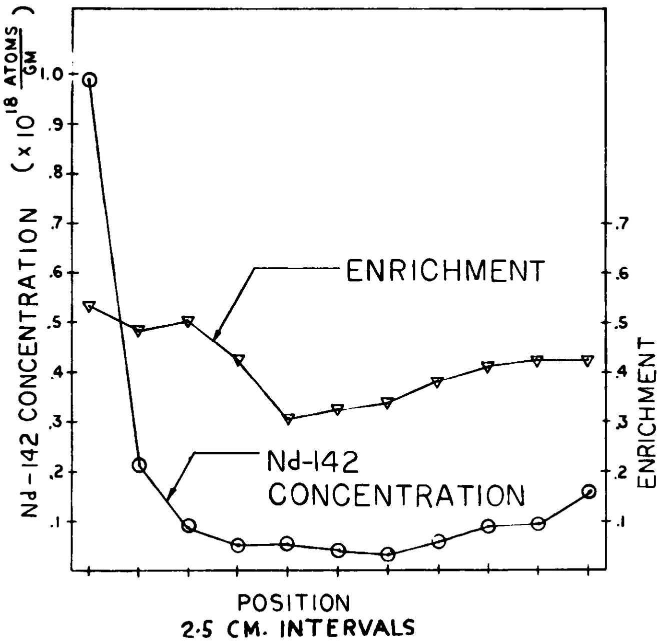

Figure 1. A graph of the Nd-142 concentration and the enrichment versus position in the reactor zone. The data plotted are the data given by Cowan et al.[2] for the 2′P′ traverse of reaction zone 2. The points plotted are about 2.5 cm apart.

ed these amounts of energy in two months and 5.4 years, respectively, operating at full power. The conventional model requires more energy to have been produced since two billion years ago the percentage of uranium that is U-235 would have been 3% instead of 0.72%, with the result that more fission had to occur.

IV. The Effective Multiplication Factor for the Neutron Population

It is commonly stated in texts on nuclear engineering that it is not possible to build a working nuclear reactor with the combination of natural uranium (0.72% U-235) as fuel and ordinary water as the moderator. The uranium must be enriched to at least about 1% U-235. While the author does not dispute this fact, it should be pointed out that the Oklo reactors did not have to produce continuous electrical power, or to be designed to be an efficient nuclear power plant. For example, the reactors could have operated in spurts, governed by the ground water concentration as a function of time, with the time between operations being used for fission product poisons (substances with a large probability of unproductively absorbing neutrons) to decay away. Kuroda[9] applied the four factor formula for the infinite multiplication factor K_∞ and concluded that uranium ore with an enrichment of 0.72% was nuclear physically "stable", i.e. could not become a reactor. However, his analysis assumed that the fast fission factor ϵ was exactly 1.0. Also, the numerical analysis of the effective multiplication factor can be improved for a water-moderated, low enrichment system by taking into account epithermal fission in the manner outlined by Glasstone and Sesonske.[10] Let us go through such an analysis for various water concentrations in the Oklo ore.

Let r be the ratio of the % water by weight to the % uranium by weight in the ore. As a rough approximation, we may ignore the presence of other substances besides water and uranium oxides. Then, by assuming various values for r, it is fairly straightforward to calculate the effective multiplication factor using Glasstone and Sesonske's method. The only problem has to do with the fact that we do not have known, regular sizes of fuel pellets or water channels. In calculating the effective resonance integral, we may use the approximation outlined by Glasstone and Edlund.[11] To find the buckling, B^2, we can calculate the geometric buckling by assuming the reactor zone was a cube with a side length $a = 1$ meter. Although the shapes seem to have been irregular[1,2], this seems to be a reasonable size and approximation. Then we get

$$B^2 = 3\left(\frac{\pi}{a}\right)^2 = 3\left(\frac{\pi}{100_{cm}}\right)^2 = 3.0\times 10^{-3}\ cm^{-2} \qquad (2)$$

The rest of the calculations are straightforward, except that of the fast fission factor, ϵ. In a low enrichment, water moderated case, as Weinberg and Wigner[12] have pointed out, neutrons which leave one fuel element have a reasonable probability of causing fission in neighboring fuel elements. This is called the "interaction fast effect". An assumption of $\epsilon = 1.0$ is thus not justified. Also, the fuel in our natural reactor cannot be said to be placed in a regular array of fuel elements, and cannot be characterized by just one parameter (such as the volume of the water divided by the volume of the fuel parameter used by Glasstone and Sesonske for the regular lattices they considered). It might be informative to imagine the fuel to be small spheres of uranium bordered by water in some directions, but touching other spheres of uranium in other directions, forming irregular "blotches". In any case, the maximum that the fast fission factor could be expected to be is about 1.2. If we assume this value, Table 1 shows the values we get for the infinite multiplication factor, k_∞, self-consistent with the value of B^2 given by Eq. 2 and with an effective multiplication factor, k_{eff}, equal to one. Thus, it is seen that criticality can be attained under these conditions, hence our theory of a recent age for the reactor is reasonable.

Conclusions

It can be said on the basis of the arguments given here that there is nothing in the neodymium and uranium concentration data that prevents us from interpreting the Oklo reactor as a recent phenomenon, having occurred only several thousand years ago. When the concentration of natural uranium was large enough, there does not seem to be anything that would have precluded a natural reactor from starting up when the water concentration was right. Thus the Oklo phenomenon is consistent with a young age of the earth. Further work needs to be done to see if it can be proven on the basis of numerical analysis that the young age model of the Oklo reactor is the only plausible one.

Appendix A

In this appendix, we will explain the calculation of

Table 1. Reactor Parameters

r	.06	.08	.1	.2
ϵ	1.2	1.2	1.2	1.2
p_{28}	.73	.77	.79	.86
p_{25}	.98	.98	.99	.99
η	1.33	1.33	1.33	1.33
f	.93	.91	.89	.79
k_∞	1.10	1.12	1.12	1.09

the effective multiplication factor in more detail. In order to take into account fissions caused by epithermal neutrons (neutrons which have not quite slowed down to thermal energies), a method such as that of Glasstone and Sesonske[10], which is an improvement over the usual six factor formula, may be used. In this method, the infinite multiplication factor k_∞ is given by the equation:

$$k_\infty = \eta f \epsilon p_{28} p_c \beta \tag{3}$$

Here η is the reproduction factor, f is the thermal utilizaton factor, ϵ is the fast fission factor, p_{28} is the overall capture escape probability for the U-238, p_c is the capture escape probability in materials other than uranium (here approximated as 1.0), and β is calculated from p_{25} (the capture escape probability for U-235) in the manner given by Glasstone and Sesonske. The values of these parameters in our case are given in Table I. These values given in Table I support a value of k_∞ bigger than one, and are consistent with a value of the buckling, B^2, appropriate to the Oklo reactor zones. Since these values were found using an enrichment of 0.72% U-235, they show that a self sustaining chain reaction could have occurred in the Oklo ore even if the enrichment was only 0.72%, hence in recent times. Thus we find that the effective multiplication factor calculations are consistent with a young earth model.

References

[1]Cowan, George A., 1976. A natural fission reactor. *Scientific American* 235(1): 36-47.
[2]Cowan. G.A., *et al.*, 1975. Some United States Studies of the Oklo Phenomenon, IAEA-SM-204/5, The Oklo Phenomenon. International Atomic Energy Agency, Vienna. Pp. 341-356.
[3]Whitcomb, J.C. and H.M. Morris, 1961. The Genesis Flood. Presbyterian and Reformed Publishing Co., Grand Rapids, Michigan.
[4]Vandenbosch, R. and J.R. Huizenga, 1973. Nuclear fission. Academic Press, New York. Pp. 309-312.
[5]Knolls Atomic Power Laboratory Chart of the Nuclides, Revision 12, 1977.
[6]Gentry, R.V., 1973. Radioactive halos, *Annual Reviews of Nuclear Science* 23. Academic Press, New York. Pp. 347-362.
[7]Baumgardner, J., 1981. private communication.
[8]Dienes, G.J. and Damask, A.C., 1958. Radiation enhanced diffusion in solids, *Journal of Applied Physics* 29(12):1713-1721.
[9]Kuroda, P.K., 1956. On the nuclear physical stability of the uranium minerals, *Journal of Chemical Physics* 25(4):781-782.
[10]Glasstone, S. and A. Sesonske, 1967. Nuclear reactor engineering. Van Nostrand Reinhold Co., Princeton. Pp. 200-209.
[11]Glasstone, S. and M.C. Edlund, 1952. The elements of nuclear reactor theory. D. Van Nostrand Co., Princeton. Pp. 256-257.
[12]Weinberg, A.M. and E.P. Wigner, 1958. The physical theory of neutron chain reactors. University of Chicago Press, Chicago. Pp. 721-722.

Reality: Real or Conventional?

(Continued from page 68)

countered the long-age theories was one of rejection, partly because this position goes contrary to years of indoctrination both from the mass media, and his elementary, high school, college, and graduate school training. Further, almost every book produced by the secular press implicitly assumes the long-age belief structure. As I explored this area further, I found the matter was not so straightforward as many of us assumed, and there is some evidence for the short-age position and there are problems with some, if not many, of the arguments for the long-age position. Likewise, with my initial exposure to the geocentric ideas, it seemed that serious discussion in support of this was unthinkable. Further extensive reading and discussion about these topics though, caused me to conclude that my earlier judgement was premature. In some areas I have had to rescind both verbal and published statements. Hopefully, these experiences will make me more cautious in the future and more apt to listen carefully to both sides of an argument before I take a position—and then caution should encourage me to always take a tentative position, and to continue to look at both sides.

Summary and Conclusion

In summary, a complex indoctrination process causes most people to develop a certain world-view which may or may not be congruent with reality. Because most of the mass media, schools and the social environment as a whole are fairly consistent in what they indoctrinate,

(Continued on page 39)