Nuclear georeactor origin of oceanic basalt $^3He/^4He$, evidence, and implications

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Nuclear georeactor numerical simulation results yield substantial ^3He and ^4He production and $^3He/^4He$ ratios relative to air (R_A) that encompass the entire 2-SD (2σ) confidence level range of tabulated measured $^3He/^4He$ ratios of basalts from along the global spreading ridge system. Georeactor-produced $^3He/^4He$ ratios are related to the extent of actinide fuel consumption at time of production and are high near the end of the georeactor lifetime. Georeactor numerical simulation results and the observed high $^3He/^4He$ ratios measured in Icelandic and Hawaiian oceanic basalts indicate that the demise of the georeactor is approaching. Within the present level of uncertainty, one cannot say precisely when georeactor demise will occur, whether in the next century, in a million years, or in a billion years from now.

helium | mantle | nuclear reactor | Earth core

Early in 1939, Hahn and Strassmann (1) published their discovery of nuclear fission. Later in the same year, Flügge (2) speculated on the possibility that self-sustaining nuclear fission chain reactions might have taken place under natural conditions within uranium ore deposits. Applying Fermi's nuclear reactor theory (3), in 1956 Kuroda (4) demonstrated the feasibility that thick seams of uranium ore might have undergone sustained nuclear fission 2,000 million years ago or earlier when the relative proportion of ^{235}U was greater. In 1972, French scientists (5) discovered the intact remains of a natural nuclear fission reactor that had operated 1,800 million years ago in a 0.5-m-thick seam of uranium ore at Oklo, in the Republic of Gabon. Later other reactor zones were discovered in the region (6). In 1992, Herndon (7), applying Fermi's nuclear reactor theory, demonstrated the feasibility of planetary-scale nuclear fission reactors as energy sources for the giant outer planets, three of which radiate approximately twice as much energy as they each receive from the Sun. Beginning in 1993, Herndon (8–10) demonstrated the feasibility of a planetary-scale nuclear fission reactor at the center of the Earth as the principal energy source for the geomagnetic field and as a contributive energy source for other geodynamic processes, such as plate movement. In 2001, Hollenbach and Herndon (11) published results of numerical simulations of a deep-Earth nuclear fission reactor, conducted at the Oak Ridge National Laboratory in Oak Ridge, TN, which confirmed the previous considerations of Herndon (8–10) and demonstrated that ^3He and ^4He would be produced by the georeactor.

Clarke *et al.* (12) discovered that ^3He and ^4He are venting from the Earth's interior. The $^3He/^4He$ ratio of helium released to the oceans at midoceanic ridges is about eight times greater than in the atmosphere ($R/R_A = 8 \pm 1$, where R is the measured value of $^3He/^4He$ and R_A is the same ratio measured in air $= 1.4 \times 10^{-6}$), and, therefore, cannot be ascribed to atmospheric contamination. Iceland plume $^3He/^4He$ values have been found (13) as high as $\approx 37\ R_A$. Natural radioactive decay of uranium and thorium will lead to ^4He production; but for three decades geophysicists have been unaware of any mechanism deep within the Earth that can account for substantial ^3He production. Lacking knowledge of a deep-source production mechanism, deep-Earth ^3He has been assumed to be of primordial origin (12, 13), trapped within the mantle at the time that the Earth formed. In the belief that deep-Earth ^3He is primordial, various implications have been drawn concerning mantle structure and dynamics (14, 15). But the ratio of primordial $^3He/^4He$ is thought to be $\approx 10^{-4}$, a value inferred from gas-rich meteorites (16), which is ≈ 1 order of magnitude greater than helium released from the mantle. In ascribing a primordial origin to the observed deep-Earth $^3He/^4He$, the assumption implicitly made is that the primordial component is diluted by a factor of ≈ 10 with ^4He produced by the natural radioactive decay of U and Th in the mantle and/or in the crust. The alternative suggestion (17), that the $^3He/^4He$ arises instead from cosmic dust, subducted into the mantle, necessitates the assumption that the influx of interplanetary dust particles was considerably greater in ancient times than at present and also necessitates the assumption of a 10-fold dilution by ^4He. Based on nuclear reactor numerical simulation results, Hollenbach and Herndon (11) have suggested instead that the observed deep-source helium is in fact the product of and evidence for a deep-Earth nuclear fission reactor (8–10).

Previous georeactor numerical simulations by Hollenbach and Herndon (11) were conducted at a single power level with the SAS2 analysis sequence contained in the SCALE Code Package from the Oak Ridge National Laboratory (18). Because these codes were developed for use with government and commercial nuclear reactors, cumulative fission yields are reported over time. The $^3He/^4He$ values published by Hollenbach and Herndon (11) were likewise cumulative. But instantaneous values are more geophysically representative and more revealing. One purpose of the present article is to present instantaneous helium fission yields ratios through steps in time at multiple power levels, thus facilitating comparison with $^3He/^4He$ ratios measured in deep-source lavas. Another purpose of the present article is to show that the nuclear reactor fission yield helium isotope ratios are not necessarily constant, but rather appear to be related to the extent of actinide fuel consumption at time of production. Still another purpose of the present article is to address the question of the georeactor lifetime and demise.

Methodology

The background as to why a large portion of the Earth's reservoir of uranium is expected to exist in the core, precipitate, and ultimately collect at the center of the Earth has been set forth in refs. 8–11 and stems from the deep interior of the Earth having a state of oxidation similar to the Abee enstatite chondrite (10). The numerical simulations presented in this article were conducted at the Oak Ridge National Laboratory by using the same computer codes and input parameters as described in Hollenbach and Herndon (11), the source to refer to for details.

Calculations were made with the SAS2 analysis sequence contained in the SCALE Code Package from the Oak Ridge National Laboratory (18) that has been developed over 30 years and has been extensively validated against isotopic analyses of commercial reactor fuels (19–23). The SAS2 sequence invokes

Abbreviations: R_A, ratio relative to air; TW, Terra-watt.

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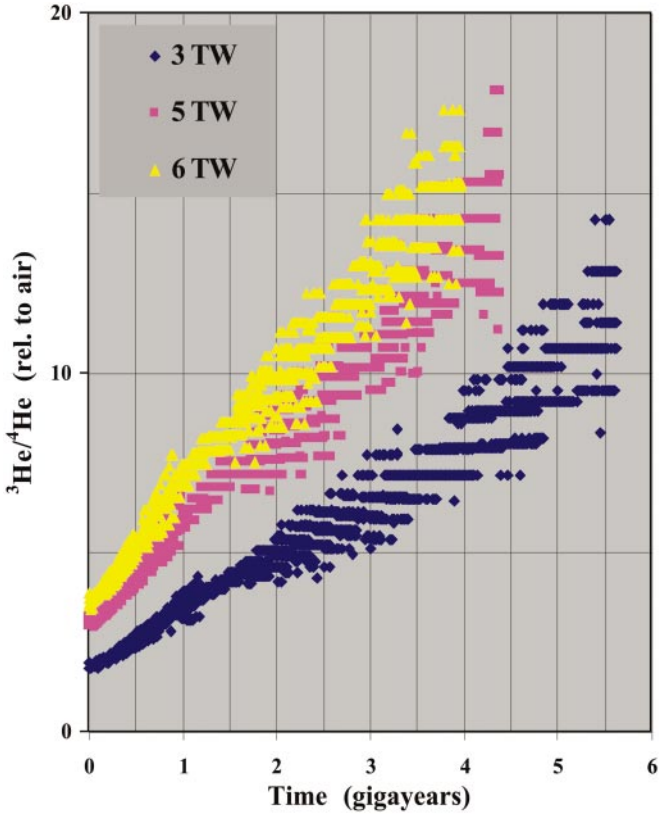

Fig. 1. Nuclear reactor numerical simulation results for three power levels showing the ^{3}He/^{4}He R_As produced during 2×10^6-year increments over the lifetime of the georeactor. Each data point represents the ratio of the ^{3}He and ^{4}He fission yields for a single time step. The pronounced upward trend of the data results from the continuing reduction of ^{238}U, the principle source of ^{4}He, by decay and breeding.

the ORIGEN-S isotopic generation and depletion code to calculate concentrations of actinides, fission products, and activation products simultaneously generated through fission, neutron absorption, and radioactive decay. The SAS2 sequence performs the 1D transport analyses at selected time intervals, calculating an energy flux spectrum, updating the time-dependent weighted cross sections for the depletion analysis, and calculating the neutron multiplication of the system.

With the exception of power levels, the values used as input to the SAS2 are the same used by Hollenbach and Herndon (11) and are as follows: initial volume of uranium = 5.6807×10^{17} cm^3; initial atom ratio ^{235}U/^{238}U = 0.3038; uranium density = 36.84 g/cm^3; steady-state fission power = 3.0 Terra-watts (TW) (3.0×10^{19} ergs/s), 5.0 TW, or 6.0 TW. Time steps of 2×10^6 years were used throughout. Reactor operation was assumed to have commenced 4.5×10^9 years ago and ceased when the effective neutron multiplication constant $K_{\text{eff}} < 1$ (3). In each case, fission products were removed on formation; all ^{3}H is assumed to have escaped the high neutron flux of the subcore reactor region before decaying to ^{3}He.

Results and Discussion

From the Oak Ridge National Laboratory numerical simulations, values of the ^{3}He/^{4}He ratio, relative to the same ratio in air, R_A, at each 2×10^6 year time step for each power level are shown in Fig. 1. For comparison, the range of values of the same ratio, measured in oceanic basalts, is shown in Table 1 at a 2σ confidence level. The entire range of values from oceanic basalts, shown in Table 1, are produced by self-sustaining nuclear fission chain reactions as demonstrated by the georeactor numerical simulations results presented in Fig. 1. The agreement is extremely strong evidence for a deep-Earth nuclear reactor and the solution of the three-decade-long mantle helium controversy and is unlike the alternative view, which rests on assumptions.

Table 1. Statistics of ^{3}He/^{4}He relative to air (R_A) of basalts from along the global spreading ridge system at a 2-SD (2σ) confidence level

Propagating lithospheric tears	11.75 ± 5.13 R_A
Manus Basin	10.67 ± 3.36 R_A
New rifts	10.01 ± 4.67 R_A
Continental rifts or narrow oceans	9.93 ± 5.18 R_A
South Atlantic seamounts	9.77 ± 1.40 R_A
Mid-Ocean Ridge Basalt	8.58 ± 1.81 R_A
EM Islands	7.89 ± 3.63 R_A
North Chile Rise	7.78 ± 0.24 R_A
Ridge abandoned islands	7.10 ± 2.44 R_A
South Chile Rise	6.88 ± 1.72 R_A
Central Atlantic Islands	6.65 ± 1.28 R_A
HIMU Islands	6.38 ± 0.94 R_A
Abandoned ridges	6.08 ± 1.80 R_A

Adapted from ref. 24.

In Fig. 1, the upward trend over time of the ratio data for each power level is principally the consequence of the gradual removal of ^{238}U, the major source of ^{4}He, by way of its natural decay and by its conversion to transuranic actinide fuels (a process of neutron absorption and β-decay termed fuel-breeding). For a particular power level, the highest ^{3}He/^{4}He values represent the most recent production, especially near the end of the nuclear fission lifetime of the georeactor.

The limitation on the upper limits for ^{3}He/^{4}He depends on the georeactor being critical, i.e., able to sustain chain reactions (3), as its actinide fuel approaches depletion. The main factors affecting that circumstance are the amount and nature of the initial actinide subcore and the operating history of the georeactor.

For the present investigation, no special efforts were made to extend the range of ^{3}He/^{4}He values, for example by assuming variable power levels over time or by including ^{232}Th. One may reasonably expect, therefore, that the high values for ^{3}He/^{4}He, shown in Fig. 1, may not be true upper limits. As with the range of isotope ratios, the number of atoms of ^{3}He and ^{4}He produced by the georeactor numerical simulations over the lifetime of its criticality, as shown in Table 2, may likewise not be true upper limits. The initial uranium content used for the nuclear reactor numerical simulations is close to the maximum one might reasonably expect. Thorium, however, was not included because of uncertainties in its abundance in the core (11) and may provide additional fissile material by transmuting to ^{233}U by neutron capture and double β-decay. But at the present time no one knows georeactor power level history, and, hence, fuel consumption in the past. Ultimately, one may hope to narrow the uncertainty by improved understanding of oceanic basalt helium data and a deeper knowledge of nuclear georeactor boundary conditions and dynamics.

Table 2. For each power level, over-lifetime-of-georeactor production of ^{3}He and ^{4}He, in atoms, time of reactor demise, and over-lifetime-of-georeactor ratios of ^{3}He/^{4}He

	^{3}He atoms	^{4}He atoms	Demise in years	^{3}He/^{4}He R_A
3 TW	1.73×10^{36}	2.59×10^{41}	5.6×10^9	4.77 R_A
5 TW	2.21×10^{36}	2.26×10^{41}	4.4×10^9	6.99 R_A
6 TW	2.39×10^{36}	2.14×10^{41}	4.0×10^9	7.98 R_A

Table 3. Potential in-core nuclear fission signatures in oceanic basalts

Isotopes	Nuclear data	Deep-earth data
^{3}He, ^{4}He	Have	Have
^{6}Li, ^{7}Li	Have	Need
^{9}Be, ^{10}Be	Have	Need
^{10}B, ^{11}B	Need	Need
^{20}Ne, ^{21}Ne, ^{22}Ne	Need	Have

Previously, in the absence of knowledge of a deep-Earth production mechanism for ^{3}He, the assumed primordial origin of ^{3}He was essentially taken as fact with little justification. In light of the evidence presented for a deep-Earth nuclear reactor origin of the ^{3}He/^{4}He of oceanic basalts, the burden of proof now falls on those who would still argue for a primordial or cosmic origin to show in detail the specific geophysical circumstances whereby their individually assumed separate helium reservoirs, differing in space and time and differing by nearly an order of magnitude, mix to yield the relatively narrow range of ^{3}He/^{4}He values shown in Table 1.

Conclusions previously drawn relating to the geophysical implications of oceanic basalt helium data, for example, mantle degassing, should now be reassessed. Such reassessment is beyond the intent and scope of the present paper. Nevertheless, the subject of high ^{3}He/^{4}He values in certain measurements of so-called plumes, specifically Icelandic and Hawaiian, deserves comment.

For years efforts have been made to find unambiguously high ^{3}He/^{4}He values in plume-derived oceanic basalts (25, 26). A main motivation of those investigations, based on the assumed primordial origin of the ^{3}He, was to find helium least diluted by ^{4}He. Those investigations should be continued and encouraged, not for the original motivation, but because the high ^{3}He/^{4}He values may very well reflect the beginnings of the demise of the georeactor and should be investigated.

One shortcoming of oceanic basalt helium isotopic measurements is that the time of formation of the helium is unknown. But from Fig. 1, one can see that helium time of formation is important for assessing the time of demise of the georeactor. Efforts should be made to address that shortcoming, such as described below.

At the pressures that prevail within the Earth's core, density is a function almost exclusively of atomic number and atomic mass. Only very light elements might be able to escape from the core and find transport to the surface through some volcanic system. Helium is one example. When an actinide nucleus fissions, it typically splits into two heavy fragments. But once in approximately every 10^{4} binary fission events, the actinide nucleus splits into three pieces, two heavy fragments and one very light fragment. Tritium (^{3}H), which decays into ^{3}He, is a light fragment from ternary fission. Other ternary fission products, which should be sought and which might be found in deep-source oceanic basalts, are shown in Table 3.

All of the isotopes shown in Table 3, with the exception of ^{10}Be, are stable. Generally, light-element, ternary fission products, if radioactive, have very short half-lives. A notable exception, however, is ^{10}Be, with a half-life of 1.5×10^{6} years. Both ^{10}Be and ^{9}Be are produced by the georeactor with an initial ratio ^{10}Be/^{9}Be = 6. Although a major technological challenge, serious efforts should be made to find evidence of nuclear fission produced beryllium in high ^{3}He/^{4}He oceanic basalt samples and then to devise a means for using ^{10}Be to obtain helium time-of-formation data.

In Fig. 1, the 3-TW, 5-TW, and 6-TW nuclear reactors cease to maintain criticality at 5.6, 4.4, and 4.0 gigayears, respectively. That these times are very close to the present epoch in the lifetime of the Earth may well be cause for concern. The long-standing idea that the Earth will continue much as it has for at least another 4.5 gigayears stems from the 1940 reasoning of Birch, who could not have known of the implications (27) resulting from the 1960's discovery of nickel silicide and silicon-containing metal in enstatite chondrite meteorites. The data presented in Fig. 1 show that terminal failure of the georeactor is approaching, but that time frame is not well defined, considering the uncertainties, and might be as short as 10^{2} years or as long as 10^{9} years.

Conclusions

The helium observed for the past three decades in oceanic basalts has been demonstrated to have been produced by a nuclear reactor at the center of the Earth. The nuclear georeactor numerical simulation results, even for the simple, preliminary cases shown, yield a narrow range of ^{3}He/^{4}He R_{A}s that encompass the entire 2-SD (2σ) confidence level range of tabulated (24) measured ^{3}He/^{4}He ratios of basalts from along the global spreading ridge system and lead to substantial ^{3}He and ^{4}He production.

Nuclear georeactor produced ^{3}He/^{4}He ratios are not necessarily constant, but rather appear to be related to the extent of actinide fuel consumption at time of production. High ^{3}He/^{4}He ratios are produced near the end of the georeactor lifetime.

Nuclear georeactor numerical simulation results and the observed high ^{3}He/^{4}He ratios measured in Icelandic and Hawaiian oceanic basalts indicate that the demise of the georeactor is approaching, but the time is not yet precisely determined. As the georeactor dies, the geomagnetic field that it presumably powers after a time will begin to collapse. But unlike previous geomagnetic collapses, that have restarted and re-energized the field, a time will come when the actinide fuel of the georeactor is too diminished to initiate self-sustaining neutron-induced chain reactions; the georeactor will die and sometime thereafter the geomagnetic field will die and will not restart. At some point in time after the georeactor dies, there will be no geomagnetic field and life on Earth will never be the same. The challenge now is to determine precisely the time of georeactor demise. Within the present level of uncertainty, one cannot say whether that time will come in the next century, in the next millennium, in a million years, or in a billion years. But one thing is certain: georeactor demise will occur.

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1. Hahn, O. & Strassmann, F. (1939) *Naturwissenschaften* **27,** 11.
2. Flügge, F. (1939) *Naturwissenschaften* **27,** 402.
3. Fermi, E. (1947) *Science* **105,** 27–32.
4. Kuroda, P. K. (1956) *J. Chem. Phys.* **25,** 781–782.
5. Neuilly, M., Bussac, J., Fréjacques, C., Nief, G., Vendryes, G. & Yvon, J. (1972) *C. R. Acad. Sci. Paris* **275,** 1847–1849.
6. Gauthier-Lafaye, F., Holliger, P. & Blanc, P. L. (1969) *Geochim. Cosmochim. Acta* **60,** 4831–4852.
7. Herndon, J. M. (1992) *Naturwissenschaften* **79,** 7–14.
8. Herndon, J. M. (1993) *J. Geomagn. Geoelectr.* **45,** 423–437.
9. Herndon, J. M. (1994) *Proc. R. Soc. London Ser. A* **445,** 453–461.
10. Herndon, J. M. (1996) *Proc. Natl. Acad. Sci. USA* **93,** 646–648.
11. Hollenbach, D. F. & Herndon, J. M. (2001) *Proc. Natl. Acad. Sci. USA* **98,** 11085–11090.
12. Clarke, W. B., Beg, M. A. & Craig, H. (1969) *Earth Planet. Sci. Lett.* **6,** 213–220.
13. Hilton, D. R., Grönvold, K., Macpherson, C. G. & Castillo, P. R. (1999) *Earth Planet. Sci. Lett.* **173,** 53–60.
14. O'Nions, P. K. (1987) *J. Geol. Soc. London* **144,** 259–274.
15. McDougall, I. & Honda, M. (1998) in *The Earth's Mantle*, ed. Jackson, I. (Cambridge Univ. Press, Cambridge, U.K.), pp. 159–190.

16. Pepin, R. O. & Singer, P. (1965) *Science* **149,** 253–265.
17. Anderson, D. L. (1993) *Science* **261,** 170–176.
18. Computational Physics and Engineering Division (April 1995) *SCALE: A Modular Code System for Performing Standardized Analyses for Licensing Evaluations*, NUREG/CR-0200, Rev. 4, ORNL/NUREG/CSD-2/R4, Vols. I, II, and III, CCC-545 (Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oak Ridge, TN).
19. Hermann, O. W., Bowman, S. M., Brady, M. C. & Parks, C. V. (1995) *Validation of the SCALE System for PWR Spent Fuel Isotopic Composition Analyses*, ORNL/TM-12667 (Martin Marietta Energy Systems, Oak Ridge National Laboratory, Oak Ridge, TN).
20. DeHart, M. D. & Hermann, O. W. (1996) *An Extension of the Validation of SCALE (SAS2H) Isotopic Predictions for PWR Spent Fuel*, ORNL/TM-13317 (Lockheed Martin Energy Research, Oak Ridge National Laboratory, Oak Ridge, TN).
21. Hermann, O. W. & DeHart, M. D. (1998) *Validation of SCALE (SAS2H) Isotopic Predictions for BWR Spent Fuel*, ORNL/TM-13315 (Lockheed Martin Energy Research, Oak Ridge National Laboratory, Oak Ridge, TN).
22. Hermann, O. W. (2000) *San Onofre PWR Data for Code Validation of MOX Fuel Depletion Analyses,* ORNL/TM-1999/018, R1 (Lockheed Martin Energy Research, Oak Ridge National Laboratory, Oak Ridge, TN).
23. England, T. R., Wilson R. E., Schenter, R. E. & Mann F. M. (1984) *Summary of ENDF/B-V Data for Fission Products and Actinides,* EPRI NP-3787 (LA-UR 83–1285) (ENDF-322) (Electric Power Research Institute, Palo Alto, CA).
24. Anderson, D. L. (2000) *Geophys. Res. Lett.* **27,** 2401–2404.
25. Kurz, M. D., Jenkins, W. J., Hart, S. R. & Clague, D. (1983) *Earth Planet. Sci. Lett.* **66,** 388–406.
26. Honda, M., McDougall, I., Patterson, D. B., Doulgeris, A. & Clague, D. A. (1993) *Geochim. Cosmochim. Acta* **57,** 859–874.
27. Herndon, J. M. (1998) *Phys. Earth Planet. Inter.* **105,** 1–4.