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Deep Time Philosophy Impacts Radiocarbon Measurements

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Abstract

The late R.E. Taylor et al. have written technical materials that disparage results showing that C-14 persists in carbonaceous materials dated by secular scientists at millions of years old. Given the relatively short theoretical shelf life of C-14 of no more than 100,000 years, the presence of C-14 in such samples challenges standard age assignments. Taylor attempts to refute these C-14 results by belittling them and claiming that those who present them misunderstand the background requirements of Accelerator Mass Spectrometer (AMS) procedures during the initial phases of carbon dating. In response, we first review the required analytical and logical steps used for standard carbon dating. This allows us to pinpoint the elements necessary to determine the presence or absence of radiocarbon in a given sample, for example a Cretaceous fossil. Finally, we critique some of Taylor's arguments. We find that his attempted refutations fail due to a lack of supporting data, the presence of contrary data, the begging the question epithet, and belittling in place of substance.

Introduction

The late R.E. (Erv) Taylor and two University of California colleagues presented an argument in *Radiocarbon* (Taylor, Southon, and Santos, 2018) that those who point to radiocarbon in Cretaceous materials simply misunderstand the significance of Accelerator Mass Spectrometer (AMS) background ^{14}C measurements. They do not refer to such individuals as biblical creationists, but their rhetoric is aimed squarely at conclusions published in creation literature, most notably results from the Radioisotopes and the Age of The Earth (RATE) project. The authors' apparent intent is to discredit those and other findings which reveal that organic materials dated at hundreds of millions of years still contain measureable ^{14}C. Their motivation is easy to surmise: If genuine and widespread, this anomalous radiocarbon implies that the current dating methodology used by secular science is in serious error. The Taylor and Bar-Yosef (2014) textbook on radiocarbon dating also presents a rather unflattering rant against YEC's work with ^{14}C. The purpose of this paper is to critique the Taylor, Southon, and Santos (2018) assault on radiocarbon research published by creation researchers.

We can quickly dismiss comments that merely disparage the creationist

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outlook in that such remarks have no scientific substance. So the main issue to address from a scientific point of view is the validity of Taylor's refutations of findings that show ^{14}C throughout earth's rock layers, including material from basement Archean rocks (Taylor and Southon, 2007).

Radiocarbon Basics

We first provide a review of the basic principles used in radiocarbon dating to build a context for an evaluation of the arguments presented in Taylor, Southon, and Santos (2018). In the 1940s, chemist Willard Libby developed a method for dating organic materials using the decay of a radioisotope of carbon, i.e., carbon 14 (^{14}C, C-14, or radiocarbon) as its foundation. The method assumes that ^{14}C has been generated in earth's atmosphere for millions of years by the nuclear reaction $^{14}N(n,p)^{14}C$ in the upper atmosphere. This ^{14}C forms CO_2 that mixes with the lower atmosphere where living organisms incorporate it through photosynthesis or ingestion and metabolism. Carbon 14 decays back to ^{14}N via beta decay, i.e., $^{14}C \rightarrow {}^{14}N + e^- + \bar{\nu}$. The beta particle ($e^-$) can then be counted using a beta-counting device such as a liquid scintillation counter and the rate of beta counts per gram of carbon converted into a concentration of ^{14}C.

Today, the AMS method is used almost exclusively to measure the amount of ^{14}C in a sample. Rather than counting beta particles over a certain time interval, the AMS method counts the actual numbers of ^{14}C, ^{13}C, and ^{12}C atoms and determines their ratios. Compared to the beta-counting method, AMS systems can use smaller samples, have lower counting times and much higher sensitivity. Thus, AMS has become the preferred method of ^{14}C dating. Initially it was thought that AMS system's higher sensitivity would enable older ages to be obtained (Schmidt, F.H. et.al. 1987),

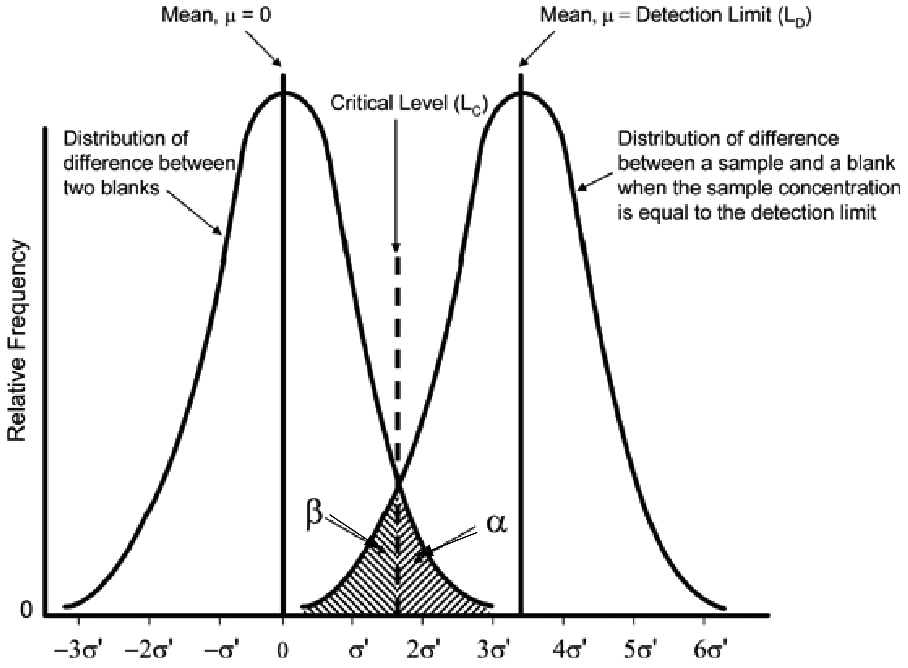

Figure 1. A schematic diagram for assessing the statistical reliability of measurements involving both a background (left-hand curve) and a sample (right-hand curve).

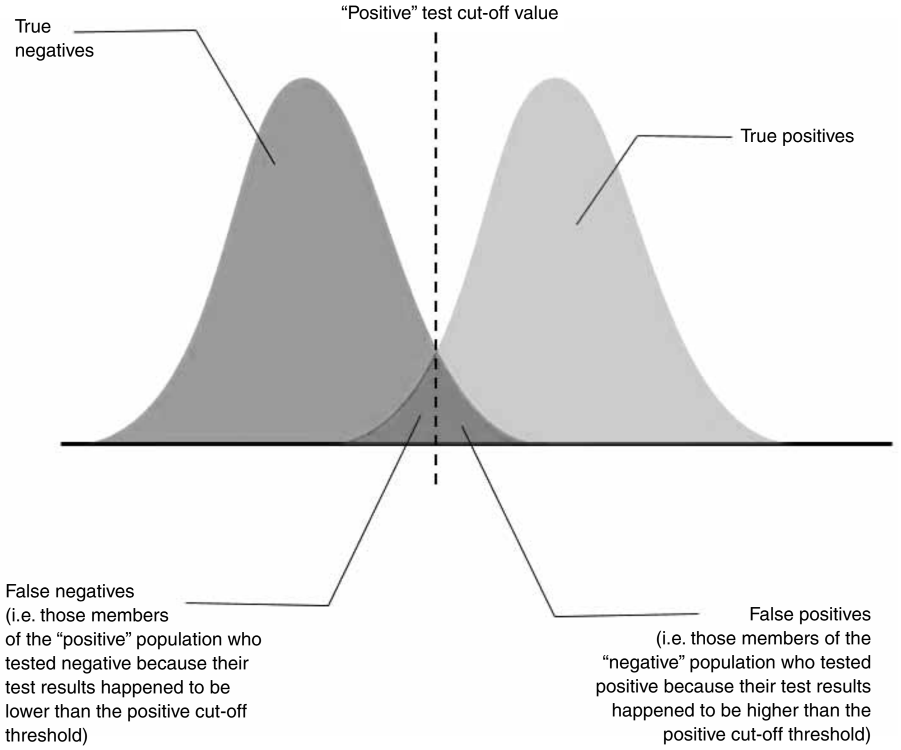

Figure 2. The limit of detection (L_D or sometimes CCβ) is the lowest concentration of ^{14}C that can be detected at a specified level of confidence. $L_D \approx (\mu_{blank} + 3 \times \sigma_{blank})$ for a 99.7% confidence that the measurand (^{14}C in this case) is present.

but problems with background measurements have dimmed those expectations.

The sensitivity of both methods is limited by what is generally referred to as "background." In the case of the beta counting method, cosmic rays cause spurious counts that are not a consequence of ^{14}C decay. In samples with very small ^{14}C concentrations, this cosmic ray background can give a comparable number of counts as actual beta particles from ^{14}C decay. Therefore, proper interpretation of radiocarbon measurements requires an accurate assessment of background levels.

In the case of the AMS method, there are several potential sources of ^{14}C. Taylor, Southon, and Santos. (2018) point out that these include both instrument based sources and sample based sources. The former arise in the hardware itself, such as electronics noise and stray ^{14}C atoms from previous runs on surfaces in the sample ionization chamber. The latter includes contributions from the several steps in laboratory sample preparation, including sample pretreatment to remove surficial contamination, the conversion of the pretreated sample to CO_2 via combustion and acid dissolution, the reduction of the CO_2 to graphite, and the transfer of the graphite to the AMS sample holder. Generally speaking, AMS labs monitor each of these sources of spurious ^{14}C carefully and keep their levels extremely low.

The general equation commonly used to convert the ratio of daughter to parent isotopes of a given (typically igneous rock) rock sample into an age does not apply to ^{14}C dating because the daughter nucleus, ^{14}N, is extremely mobile and abundant in earth environments. So, in order to date organic matter or carbonaceous artifacts using the decay of ^{14}C as a clock, a more complicated equation must be used. If we can measure the current amount of ^{14}C (i.e., the $^{14}C/^{12}C$ ratio) in a given sample and if we also assume an accurate estimate of the amount of the $^{14}C/^{12}C$ that was in the sample originally, then we can calculate a carbon age of the sample using the equation:

$$\frac{1}{\lambda} ln \frac{N_0}{N_p} = t_a \tag{1}$$

where N_p is the present amount of ^{14}C (N = nuclei) in the sample, N_0 is the amount of ^{14}C originally in the sample and assumed to be proportional to the $^{14}C/^{12}C$ of the international radiocarbon standard, and λ is the decay constant for ^{14}C. The amount of ^{14}C currently in any given sample can in principle be measured either by beta particle counting spectroscopy or an AMS system. However, problems begin to emerge when one attempts to estimate N_0 for a given sample. The amount of ^{14}C accumulated in any living organism during the photosynthesis process (for plants) or the metabolism of food (for animals) and remaining when it dies (N_0) depends on time and environment. For example, increased use of fossil fuels with the advent of the industrial revolution in the eighteenth century began diluting the concentration of ^{14}C in the atmosphere with ^{12}C. This lowered the prior normal ratio of ^{14}C to ^{12}C in terrestrial living organisms. Similarly, nuclear testing that began in 1945 created non-cosmogenic ^{14}C that increased the ^{14}C to ^{12}C ratio in the atmosphere as well as in living organisms. These variables illustrate the challenge of assuming an accurate estimate for N_0 of a long-dead organism, which assumption becomes increasingly tenuous with possibly more unknown variables in increasingly older samples.

Because of difficulties in determining N_0, values for ^{14}C content are generally reported as either the corrected percent modern carbon (pMC*) [pMC* ≡ (sample-background)/(modern-background)] x 100% or the uncorrected percent modern carbon (pMC) [pMC ≡ (sample/modern)] x 100%. The "modern" ^{14}C is the 1850 ^{14}C value (N_0) normalized to 1950.

Evaluating Measurements

Measurement science requires an evaluation of two basic parameters in the measuring device: the sample background and the sample itself. The experimenter needs an accurate evaluation of the ^{14}C background in order to establish an intrinsic ^{14}C concentration for an organic sample. Likewise, workers must assess whether the background measurements rise sufficiently above the detection limits of the measuring apparatus to achieve statistical significance. Figures 1 and 2 schematically illustrate this concept. Proper reporting of ^{14}C measurement results should include error bars on both the sample and the sample blank. These error bars ought to include systematic as well as statistical errors. The mean values for the sample blank and the sample then serve as the apex or height of Gaussian curves describing each, while the width of each curve (σ) is given by the error bars of the measurement. Once constructed, these curves permit statistical evaluation of sample measurements. A 95% (2 sigma) or 99.7% (3 sigma) confidence level means that the sample measurement area is 95% or 99.7% beyond the area defined by the sample blank. The limit of detection (L_D) for a given measurement equals the sample blank mean value + 1.645 x the sample blank error (σ_b), or mathematically, $S_b + 1.645 ^x \sigma_b$. For a 99.7 % confidence in the limit of detection, 3 is substituted for 1.645 in the above equation. This is also colloquially referred to as a 3 sigma confidence level. In our experience, most of the basic measurements of isotope ratios in ^{14}C dating do not include potential systematic error analyses or a statistical evaluation of their data.

Real Radiocarbon Misunderstandings

The presence or absence of intrinsic ^{14}C can be reasonably ascertained from measurements once the ^{14}C background has been accurately measured. Note that thus far no attempt to estimate the age of a sample has been made or is even necessary to draw a reasonable conclusion about the presence or absence of residual (intrinsic) ^{14}C in that sample. However, Taylor, Southon, and Santos (2018) start their argument by defining all ^{14}C sample measurements to fall into either infinite age or finite age categories. They thereby bias the discussion in favor of the deep time paradigm so popular among secular scientists. Uniformitarians describe a sample of *infinite age* as one "for which it can be reasonably assumed," with confidence, that all intrinsic or residual ^{14}C that it originally contained has long decayed away (Taylor, Southon, and Santos, 2018)—for example Pennsylvanian System coals with assigned ages of hundreds of millions of years. They then use this deep-time assumption, not measurements or data, to conclude that any ^{14}C detected in an infinite age sample must be due to contamination or improper background determination.

Taylor, Southon, and Santos (2018) assert that those who interpret ^{14}C measured in infinite age samples as intrinsic to the sample rather than implicating contamination or improper background determinations are knowledge deficient in one or more of these four areas:

i. The definition and implications of "backgrounds" and "sample blanks" employed in AMS-based measurements,
ii. understanding the difference between finite and infinite ^{14}C age determinations,
iii. the distinction between "machine-based backgrounds" and "sample-based backgrounds" in creating net background values unique for each AMS system measuring natural ^{14}C and,
iv. the effects of trace amounts of modern or near modern contamination on measured ^{14}C values when dealing with infinite age samples.

We now address each of these so-called deficiencies:

i) Ignorance of "backgrounds" and "sample blanks"

In all machine-based measurements, the total background is a combination of that which originates from the machine and the environment plus that which originates from a sample blank. This is standard throughout many industries and is the reason why sample blanks must be chosen wisely. Ideally, if one is going to measure ^{14}C in a given organic sample then a sample blank identical to the actual sample in every way but devoid of ^{14}C should be chosen. Organic samples would fit that profile if they really were millions of years in age. If the sample blanks are more recent than deep time proponents assert, then one should choose a sample blank as close to or below the AMS sensitivity limits as possible. Thus, if the sample blanks are not as old as Taylor and colleagues insist, then it is their knowledge that is deficient, rather than that of those they accuse of ignorance. Simply put, if sample blanks can be found or manufactured with a lower $^{14}C/^{12}C$ ratio than the supposed infinite age sample blanks, it suggests that those supposed infinite age samples are not of infinite age after all.

ii) Ignorance of finite and infinite ^{14}C ages

This supposed deficiency begs the question at hand, i.e., AMS background ^{14}C measurements. The concepts of finite and infinite time ^{14}C age determinations are arbitrary definitions coined by the secular community. They have nothing to do with the proper measurement of ^{14}C in terrestrial samples of organic materials, and even less to do with determining the presence or absence of radiocarbon in a sample. The more relevant question concerns whether the "infinite age" samples are actually infinitely old in carbon years. This question should be settled by data, not assumption.

iii) Ignorance of "machine-based backgrounds" versus "sample-based backgrounds"

Generally, there is no distinction between "machine-based backgrounds" and "sample-based backgrounds" in creating a net background to subtract from the ^{14}C sample if the measurement was done according to normal protocols. The distinction only exists for the experimenter who is attempting to obtain an accurate evaluation of net background contributions. The primary contributors to the net background are most often sample-based. Sample-based backgrounds are the more appropriate for use in the formula given above for pMC*. It is fair to question if variations in backgrounds from the machine and the sample blank can impact measurement of a sample's residual (intrinsic) ^{14}C content. Experimental data is only as reliable as its repeatable experimental methodology. Perhaps the best evidence of this is that samples that were measured, processed in the prescribed way, and re-measured can have higher $^{14}C/C$ ratios after reprocessing. For example, Arnold et al. (1987) took graphite, which had a measured $^{14}C/C$ ratio of 0.089 ± 0.017 pMC when placed on a sample holder, oxidized it to CO_2, reduced it back to elemental carbon, and put that on a sample holder. That same graphite sample now measured a higher $^{14}C/C$ ratio of 0.34 ± 0.11 pMC. Clearly, the added radiocarbon came from the laboratory environment. A similar experiment by Van Der Borg et al. (1997) observed a graphite sample going from 0.04 ± 0.02 pMC before processing to 0.18 pMC after processing. These two experiments suggest that in equivalent laboratories, laboratory processing can add 0.14 to 0.25 pMC which is not negligible when evaluating samples with small residual radiocarbon amounts, such as coal.

Unfortunately, this kind of experiment is not often recorded in the literature, and sometimes one has to use less direct methods to determine how much laboratory contamination is routine. Middleton et al. (1989) measured CO_2 directly, produced by dolomite, at 0.01 pMC when handled with extreme care and 0.5 pMC when handled with less care. Schmidt et al. (1987) reported several graphite samples that varied in their $^{14}C/C$ ratio depending on the care used in lab preparation. They even noted a finite "age" (0.05 pMC) for ^{12}C from a Faraday cup in their AMS machine, which was effectively functioning as a mass spectrometer to separate ^{12}C from ^{14}C. Even these trace contributions, when compared with the relatively higher ratios of supposedly ancient samples, argues quite strongly for the existence of residual (intrinsic) radiocarbon in so-called "infinite age" samples. Such radiocarbon content is incompatible with age assignments greater than 100,000 years. This is because a properly done measurement subtracts the total background from the measured sample. A detailed discussion of AMS backgrounds used in ^{14}C measurements can be found in Baumgardner (2005) and Baumgardner et al. (2003). In these references a background standard of 0.077 ± 0.005 percent modern carbon (pMC) constructed from purified natural gas CO_2 was used in determining the ^{14}C content of coal samples that should be radiocarbon dead. The pMC unit defines the N_0 or original ^{14}C as 95% of the radiocarbon concentration (in AD 1950) of NBS Oxalic Acid I (SRM 4990B or equivalent) normalized to $\delta^{13}C_{VPDB}$ = - 19 per mil. (Stenström, et al., 2011.)

iv) Ignorance of trace amounts of modern or nearly modern contamination sources

Finally, uniformitarians should bear the burden of proof in demonstrating that (and showing how) modern radiocarbon infiltrated their sample blanks enough to raise the radiocarbon concentration so far above the theoretical sensitivity limits of a given AMS system. The question is whether "the effects of trace amounts of modern or near modern contamination on measured ^{14}C values when dealing with infinite age samples" has been taken into account (Taylor, Southon, and Santos, 2018). Taylor and coauthors mention the problem but fail to quantify it.

In principle, adding to an infinite age sample enough modern carbon (contamination) to raise the final concentration to one part modern carbon in 1,000 parts total carbon will leave a final ^{14}C concentration of exactly 0.1 pMC. It is really that straight forward. Mixing half and half would give 50 pMC. Replacing 100% of a carbon dead sample with modern carbon will give 100 pMC. If we repeat the 1/1000 exercise with 1940 carbon at 95 pMC, we get 0.095 pMC, and using actual modern carbon at approximately 110 pMC, would yield 0.11 pMC. This means that if we wish to explain dinosaur remains having a $^{14}C/C$ ratio of 3% (not unusual), we must believe that 3% of the sample has been replaced with modern carbon (or alternatively 3.1% of modern carbon has been added to the sample). Given the relatively short half-life of radiocarbon, this would require that the replacement occur within the last few years. If it occurred 5,730 years ago (the ^{14}C half-life), the corresponding numbers are 6% and 6.4%. This interesting proposal implies that the material is constantly churning new carbon into the sample. The supposed contaminant could be restricted to a defined portion of the sample, or over millions of years should replace the entire sample.

Alternatively, the supposed replacement scenario would have been limited to the last few thousand years—not a terribly uniformitarian idea. In other words, the assertion of modern contamination to explain small amounts of radiocarbon in fossils may appear reasonable until one starts to put numbers to it. At present, their reason for concluding contamination in sample blanks is merely circular. Since the sample blank is 240 million years old, it has no original radiocarbon left. But radiocarbon is detected. Therefore, the detected radiocarbon must derive from some source other than the millions-of-years-old sample. Remove the uniformitarian bias and we have samples with intrinsic radiocarbon. This would erase the need to define (rather than measure) any sample as carbon dead or as having infinite age.

Since processing can introduce measurable contamination, it would be prudent to use caution if comparing graphite, which needs no processing, with coal, which typically is processed by oxidation and then reduction in preparation for radiocarbon measurements. One way to directly compare graphite to coal is to heat the coal and measure it directly. Unfortunately, there is a dearth of reported experiments using this procedure. Table 1 summarizes the few related examples we could find in the literature.

Table 1. Published radiocarbon measurements of coal-sourced carbon.

Author	Date	Material	pMC
Beukens et al.	1982	acetylene*	0.142±0.028
Beukens	1983	acetylene	0.014±0.010
Farwell et al.	1984	cracked coal tar	0.044
Gillespie and Hedges	1984	cracked petroleum	0.1±0.05
Terrasi et al.	1990	coke	0.3

* Probably made from calcium oxide and coal

Another way to compare graphite with coal would involve processing the graphite like one would process the coal. Again, such experiments are rare; Arnold et al. (1987) and Van der Borg, et al. (1997) are two of the only three experiments we could find. The third experiment is noted below.

One can get around this problem of contamination via processing (mostly the combustion step) by showing that a particular laboratory has a very low background regardless of sample type. For example, the laboratory that used to be in Toronto had consistent backgrounds of 0.07 to 0.08 pMC for reduced samples. Another laboratory with consistently low backgrounds is Australian National University (ANU), reported by Bird et al. (1999), who describe an elaborate procedure that enabled untreated "Ceylon graphite" (Precambrian with Cambrian metamorphosis) background measurements to reach down to 0.046 pMC, (average of 9 samples). Graphite cycled through their process measured 0.04 pMC (average of 4 samples), meaning that the procedure added virtually no contaminating radiocarbon.

This level of competence cannot be attributed to other laboratories unless they also test themselves, refuting claims about all measured carbon being residual carbon. As noted above, somewhere around 0.1 to 0.3 pMC, or perhaps more, can be added to samples simply by oxidizing and then reducing it in a less optimal laboratory. Two laboratories added only 0.00 to 0.077 pMC during processing—levels that leave the RATE group data intact, as shown below. Possibly, Taylor, Southon, and Santos (2018) are referring to the ambiguity of discerning between $^{14}N^-$ and $^{14}C^-$ in the AMS ^{14}C detector. However, the authors themselves argue that negative ^{14}N ions have such a short lifetime (< a few microseconds) that they do not make it to the ^{14}C detector. Even if they did, they should be included as the average machine background which already gets subtracted from the unknown ^{14}C sample signal.

Let's now look at those sources of contamination that Taylor, Southon, and Santos (2018) list in their Table 3. Rather than theoretically discounting them, let's ask how workers could detect those sources of error. If the machine runs without a sample, one could detect target/cathode contamination and all other instrument-based sources. Specially cleaned (or naturally clean) sample runs could detect manipulation and storage sources, and possibly contamination during sample pretreatment. And if one runs a sample that was oxidized and then reduced, then combustion and graphitization sample preparation sources could be measured as well. So with the proper controls, one could empirically show that the contamination can be reduced to manageable levels. And manageable levels, not proof that all ^{14}C is residual, are all one needs to determine if a sample has residual radiocarbon or not.

ANU was at one time the best laboratory for measuring very low levels of ^{14}C, but even the lab that the RATE group used was very good. It is certainly possible to reduce laboratory contamination to a negligible level.

In summary, the argument that backgrounds are not properly understood as the reason for measureable ^{14}C in samples with millions or even billions of years' age assignments relies on the assumption of deep time, not on any measurement. Taylor and colleague's (2018) four supposed deficiencies really do not deal with the actual measurement of low levels of ^{14}C in samples or sample blanks. Rather, they focus on dating results from models that, for them, trump measurements. Conclusions drawn from observational evidence should outweigh conclusions drawn from models. Taylor, Southon and Santos (2018) fail to scientifically support their contention that the detection of radiocarbon in fossils arises from misunderstanding background measurements.

An Argumentative Diversion and a Logical Fallacy

R. Ervin Taylor was a leader in his field, and certainly deserves respect and appreciation for his involvement in the establishment of AMS systems for use in radiocarbon dating and for his expertise in working with bone in particular. However, poor reasoning including an argumentative diversion and a logical fallacy lurk near the core of his objection to measurable radiocarbon in supposedly carbon dead samples.

His *Radiocarbon* paper (2018) appears to use a shotgun argument. This refers to a disputation tactic wherein one fires so many reasons for their position that the opponent cannot respond to them all. Only one of the 16 potential sources of supposed contamination listed in Table 3 by Taylor, Southon, and Santos (2018) reflects radiocarbon endogenous (intrinsic) to the sample blank. We have no disagreement that radiocarbon could theoretically arise from any of his listed sources. However, what experimental evidence suggests that the amounts of radiocarbon detected in sample blank measurements could, let alone should, arise from any or a combination of these sources rather than arising from the blank itself? Taylor argues that since this is only one possibility out of 16, the odds favor the other 15. This shotgun argument incorrectly weights each potential source equally. The potential for ^{14}C to enter the system from such sources as the instrument components or electronic noise in the detector may be too small to account for the levels of ^{14}C routinely measured in supposedly dead carbon blanks, as shown by studies that Taylor, Southon, and Santos (2018) cite. Is their shotgun approach an attempt to mask the burden of proof they bear to demonstrate (not just assert) that the 15 potential sources from which they want extra ^{14}C to arise are actually capable of consistently supplying the levels of ^{14}C routinely detected in sample blanks?

In addition, the study authors rely on a logical fallacy called the begging the question epithet. This occurs when one concludes that which one assumed in the first place. In this case, Taylor, Southon and Santos (2018) argue in a circle when they refer to "…samples reasonably assumed to contain no measureable cosmogenic ^{14}C." What makes this assumption so reasonable? They explain, "In ^{14}C studies, a sample used for background measurements would be an organic of sufficient geological or paleontological age so that it can be reasonably assumed that, given the ^{14}C half-life of ~5700 years, all of that sample's original ^{14}C content should have been reduced to zero." This reveals faith in geological and paleontological age assignments despite deep problems with the methods its practitioners use, including discordant "ages," old "ages" for young samples, evidence of open system behavior such as accelerated nuclear decay and hydrothermal transport of parent and daughter components, and circularity. Thus, they employ circularity when they conclude that sample blanks are carbon dead on the basis of the assumption that the blanks must be carbon dead. Ironically, radiocarbon levels in their own geologically sourced radiocarbon sample blanks should challenge the very geological age assignments that they trust so implicitly.

Examples, Limits, and Backgrounds

We now take a closer look at some actual ^{14}C measurements that Taylor and colleagues call into question. These examples illustrate the principles discussed above. Multiple references (Baumgardner, et.al., 2003, Baumgardner, 2005, Snelling, (1997, 1998, 1999, 2000a, 2000b), and Giem , 2001) attest to the widespread presence of measureable radiocarbon in Phanerozoic strata. In the late 1990s Andrew Snelling (1997, 1998, 1999, 2000a, or 2000b), relying on reputable AMS laboratories, found a range of 7.58 ± 1.11 percent modern carbon (pMC) for a lower Jurassic sample, and 0.38 ± 0.04 pMC for a middle Tertiary sample. Table 5 of Taylor, Southon, and Santos (2018) show possible "infinite" carbon sample blanks. These data suggest a detection limit of 0.15 pMC for processed geological graphite, 0.12 pMC for unprocessed geological graphite, 0.17 pMC for processed coal, 0.08 pMC for unprocessed diamond, and 0.18 pMC for processed diamond to a 99.7% confidence level. The pMC notation represents the proportion of radiocarbon in a sample compared to that present in 1950—the pre-nuclear testing era and equal to "0 years before present (BP)" by convention. pMC = $100\,(0.5^{\text{C-yrs}/5568})$, where 5568 is Libby's original half-life still used by convention. Thus, 1,090 radiocarbon years BP correspond to a pMC of ~87.8, and 41,010 carbon years BP correspond to a pMC of ~1.53. If Snelling's sample results were background subtracted and we use the 0.17 detection limit from Taylor's Table 5 (Taylor, et. al. 2018), then 7.58 ± 1.11 pMC means that there is a 99.7% probability that the Jurassic sample's intrinsic pMC value is greater than 0.17 pMC and a 67% chance it lies between 5.36 and 9.80. Likewise, there is a 99.7% probability that the middle Tertiary sample's intrinsic pMC value is greater than 0.17, and a 67% chance it lies between 0.30 and 0.46 pMC.

Current AMS technology can reliably measure a ratio of 10^{-16} (0.01 pMC) and in some cases down to 0.001 pMC. This would be the sensitivity of the measurement but not the limit of detection (L_D) given above. Therefore, to a high degree of confidence, radiocarbon exists in these samples (which should be radiocarbon dead according to secular time scales). One can reasonably conclude that both the above measurements are well above the detection limits for a carefully operated AMS system.

What about the claim of these measurements, plus so many others taken from samples of supposedly infinite age, simply being background? Background is defined as the residual machine background plus the sample blank. Precambrian limestone environments typically produce ^{14}C values of 0.05 pMC (Baumgardner, 2005, p. 604), well above the sensitivity limits of AMS systems. This is a typical problem encountered in measuring very low levels of nearly ubiquitous radioisotopes, such as ^{3}H and ^{14}C, in the environment. Therefore, it is incumbent on the experimenter to maintain as clean a machine as possible and to choose the sample blank to provide the lowest possible background. Perhaps a better choice than those currently in use for a sample blank would be one of the diamonds which Taylor and Southon (2007) analyzed to monitor AMS backgrounds; specifically, sample numbers UCIAMS-9639 and UCIAMS 9640.

Since any reliable measurement must subtract known background contributors, it is reasonable to assume measurements such as those reported by Snelling, RATE, and others represent radiocarbon above the background. In fact, the results for ten RATE (Baumgardner, 2005, p. 605 and 608) coal samples each had a "standard background" of 0.077 ± 0.005 pMC subtracted from the final quoted pMC value. For this background the 99.7 % detection limit would be approximately 0.092 pMC. Thus, eight of ten measurements are still 2 to 3 times the detection limits of those AMS measurements at a 99.7% confidence level. Clearly, intrinsic ^{14}C exists in these samples. Their burial deep below ground, and thus far from solar radiation, renders contamination highly improbable (Baumgardner, 2005, p 614–615, Cupps, 2017).

Radiocarbon in Diamonds

This raises the question: Does ^{14}C exist in detectable levels for all terrestrial carbon, and if so at what levels? Natural

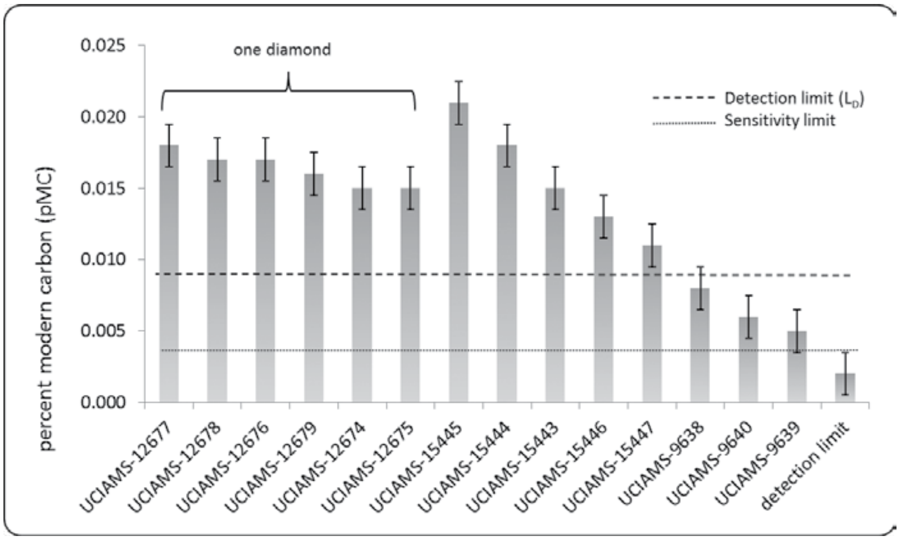

Figure 3. Background values from Taylor and Southon (2007) were used to estimate a L_D of approximately 0.8 pMC at 99.7% confidence (dashed line). Dotted line represents an AMS sensitivity limit estimate. The most parsimonious interpretation of pMC levels above both lines is that from six to ten of their ten diamonds contained intrinsic radiocarbon.

diamonds present one potential test of this hypothesis. They are formed under very high pressures only naturally realizable at depths of greater than 100 km inside the earth. They are also extremely resistant to contamination via chemical interaction with their environment. Uniformitarians believe that natural diamonds found near the earth's surface were formed 1 to 3 billion years ago in the earth's upper mantle and brought to the surface through kimberlite pipes. They would thus assert that these diamonds have been locked away from contact with the earth's atmosphere since early in earth's history. If ^{14}C with its relatively short half-life exists in measurable amounts in such natural diamonds, then it presents a significant challenge to deep time advocates.

We therefore plotted (Fig. 3) the carbon ages for diamonds using data reported by Taylor and Southon (2007) along with a typical AMS detection limit (L_D) from Table 5 in Taylor, Southon, and Santos (2018) according to the following steps. First, each reported "Fraction modern" (fm) value was converted to uncalibrated carbon years using [-8033 x ln(fm)]. Each resulting carbon age was converted back to pMC using [$100 \times 0.5^{(\text{C-yrs}/5568)}$], with 5568 being the less accurate but conventionally used Libby half-life for radiocarbon. Reading left to right, the first six bars of Fig. 3 show six replicate measurements from one diamond. The next eight bars show single measurements from eight separate diamonds. The dotted line shows a typical theoretical sensitivity limit for modern AMS instruments of 0.002 and the dashed line an approximate limit of detection (L_D) at a 3-sigma (99.7%) confidence level calculated from the Taylor and Southon (2007) data. Error bars are 1-sigma (65%) significance. Thus, the majority of R.E. Taylor's own diamond ^{14}C measurements showed intrinsic radiocarbon to a very high confidence level.

Taylor and Southon (2007) concluded from these results that the amount of radiocarbon above theoretical detection limits resulted from memory effects. However, they never provided specifics for such a hypothesis or how to test it, let alone demonstrate what feature(s) of their results are consistent with memory effects. Possibly Taylor and Southon simply declared memory effects as the cause instead of testing for or against radiocarbon being intrinsic to the diamonds. Attributing their results (Figure 3) to memory effects or any similar source of recent contamination would provide a shield behind which billion year age assignments might hide from young-looking intrinsic radiocarbon.

The RATE results add similar arguments. Six measurements, with no background subtraction, of diamonds from various African mines (Baumgardner, 2005, p. 611) displayed ^{14}C in amounts at least 10 times greater than the sensitivity limit of the AMS system and approximately 1.5 times greater than the laboratories' 99.7% detection limit of 0.08 pMC. The same AMS laboratory also performed ^{14}C measurements on 6 alluvial diamonds from Namibia (Baumgardner, 2005, p. 612). All results displayed ^{14}C in amounts significantly above AMS sensitivity limits without the "standard background" subtraction. Table 2 reproduces the RATE summary of these results. With background subtraction, the five samples from the Kimberlite pipe diamonds average out to 0.04 pMC; still at least 4 times the sensitivity limit of the AMS system. The seven alluvial samples average 0.12 pMC; at least 12 times the sensitivity limit of the AMS system and 30% higher than the 99.7% detection limit. Figure 4 displays the results for the five samples from the Kimberlite pipe and the alluvial diamond from Guinea with the lowest measured pMC along with the AMS sensitivity threshold. This experimental evidence suggests that future investigations will continue to find intrinsic radiocarbon in any terrestrial carbon source.

Table 2. AMS ^{14}C measurement results for twelve diamonds, five from the African kimberlite pipe and seven from African alluvial deposits. All have the laboratory's standard background correction (0.08 pMC) applied. Table reproduced from RATE, vol. II. (Baumgardner, 2005, p. 614).

Sample ID	Geological Setting	Country	$^{14}C/C$ (pMC)
Kimberley-1	kimberlite pipe (Kimberley)	South Africa	0.02±0.03
Orapa-A	kimberlite pipe (Orapa mine)	Botswana	0.01±0.03
Orapa-F	kimberlite pipe (Orapa mine)	Botswana	0.03±0.03
Letlhakane-1	kimberlite pipe	Botswana	0.04±0.03
Letlhakane-3	kimberlite pipe	Botswana	0.07±0.02
Kankan	alluvial deposit	Guinea	0.03±0.03
NMBclrl	alluvial deposit	Namibia	0.31±0.02
NMBclr2	alluvial deposit	Namibia	0.17±0.02
NMBclr3	alluvial deposit	Namibia	0.13±0.03
NMByel1	alluvial deposit	Namibia	0.09±0.02
NMByel2	alluvial deposit	Namibia	0.04±0.02
NMBrn2	alluvial deposit	Namibia	0.07±0.02

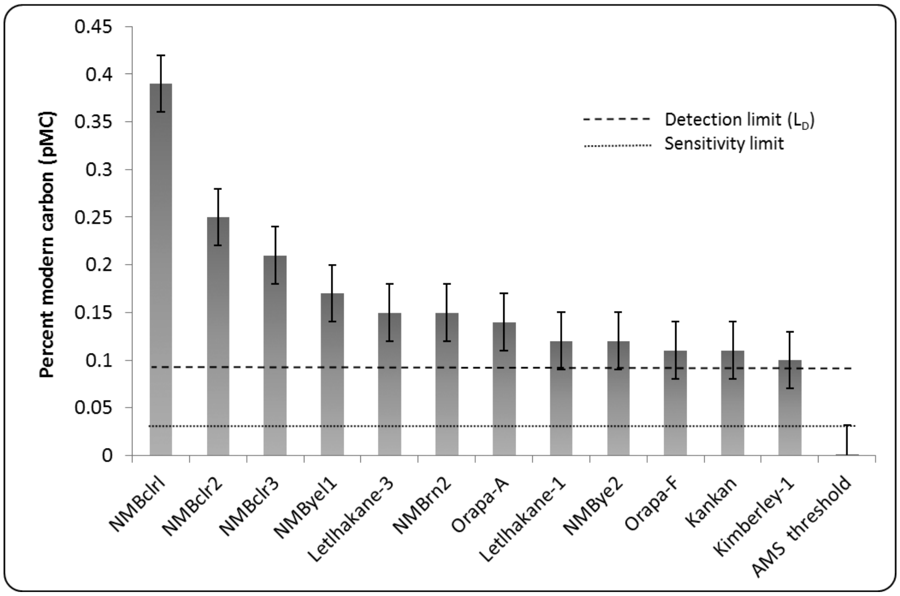

Figure 4. RATE diamonds show with 99.7% confidence that residual/intrinsic ^{14}C is present in nine of twelve measurements.

Additional examples of radiocarbon in very old carbonaceous samples including fossils could be given to demonstrate radiocarbon levels far above AMS sensitivity limits and in some cases above instrument backgrounds. Fig. 5 offers nine fossils with pMC ratios far enough above instrument background for AMS procedures to determine finite ages. All data in Fig. 5 are discussed in detail in Thomas (2019).

Conclusion

Taylor, Southon, and Santos (2018) claim that those who suggest that radiocarbon is intrinsic to geological samples misunderstand AMS background measurement principles. That thesis finds its support in the philosophical constructs of uniformitarianism, but not in measurements or science. Difficulty finding a suitable background sample appears to be a significant challenge facing radiocarbon measurements in AMS systems and not the existence of "erroneous backgrounds." To argue that all the radiocarbon measurements, which clearly demonstrate the presence of ^{14}C in material deemed to be older than 60,000 years by the secular community, arise from erroneous background assessments uses circular reasoning. It assumes that the machine blanks are carbon dead despite the fact that they consistently contain more radiocarbon than both the AMS theoretical sensitivity limit and the approximate 99.7% confidence level detection limit. Taylor, Southon, and Santos (2018) fail to address this, even though it reflects the main problem with low level ^{14}C measurements. Instead, the consistent problem of detecting radiocarbon well above instrumentation detection thresholds in a variety of supposedly carbon dead earth materials including coal, limestone, marble, and diamonds suggests that these materials have been incorrectly assigned excessive ages. An objective scientist, unbiased by uniformitarianism, would look at the

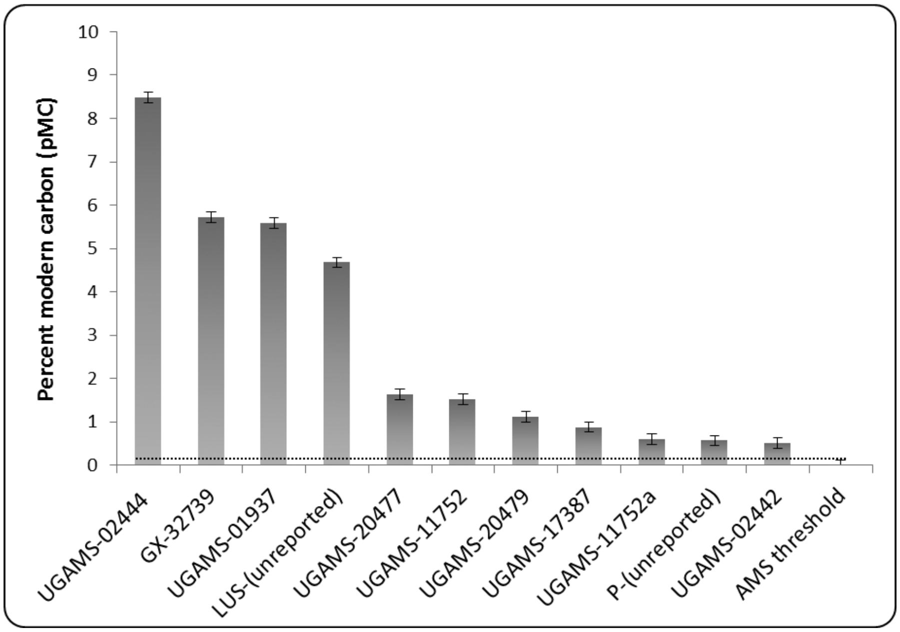

Figure 5. Eleven radiocarbon measurements of fossil samples all occur above the estimated instrument sensitivity (dashed line). Data represent four laboratories, two published results (LUS, and P), eight Cretaceous fossils, one Cretaceous matrix sample (UGAMS-02444), one Jurassic (UGAMS 20479), and one Ediacaran fossil.

evidence and seek a more plausible explanation than erroneous backgrounds or improbable contamination for ever-present radiocarbon in terrestrial material. The radiocarbon measurements that Taylor and colleagues (2014, 2018) want to dismiss suggest instead a need for a critique of standard geological dating methodologies.

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