Carbon-14 dating: Some open questions (1)

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Introduction:

This article is based upon my engineer thesis Radioactive Dating Methods, 1985 [1], where among other things I had access to all published carbon-14 datings 1949-1968 related to Egyptian history.

Survey:

Some important years and events in the history of the carbon-14 dating method:

Year	Event
1949-52	Libby's first calibration curve
1962/68 and before	Standard Egyptian chronology (Hayes/Helck)
1966	Yaku-Sugi dendrochronology
ab. 1969	Bristlecone pine dendrochronology
ab. 1970	Congress where it was decided to build the calibration curve on dendrochronology (bristlecone pine) and not Egyptian chronology [3].
ab. 1971	Courville's Egyptian chronology

Libby's first calibration curve

About 1952 [2] W. F. Libby published his carbon-14 calibration curve:

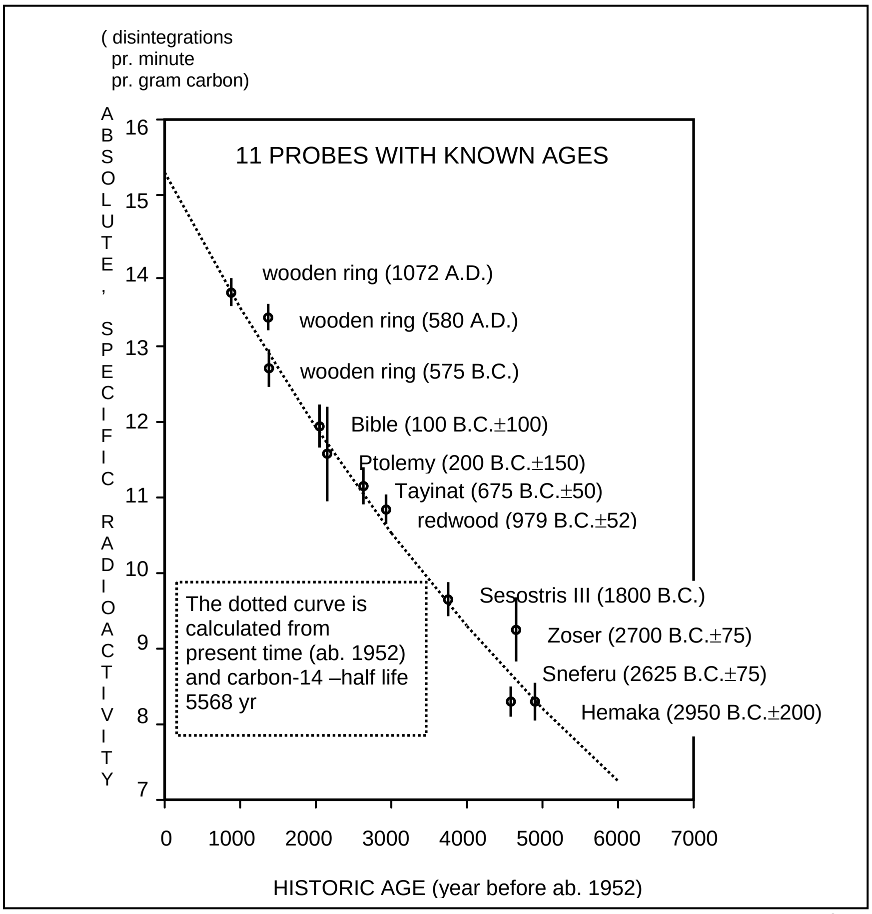

Figure 1: Libbys calibration curve (reproduced after Libby, 1952 [2])

Libbys age formula for carbon-14 dating is:

$$apparent\ age = t = \frac{5568\ yr}{\ln(2)} \cdot \ln\left(\frac{15.3}{A}\right) \qquad \text{(formula 1)}$$

Libby's age formula and curve is based upon the supposition that the activity of "fresh" wood is (at all times) [3]:

$$A_0 = 15.3 \frac{disintegrations}{gram\ carbon \cdot minute}$$

You might also formulate the supposition like this, "that the cosmic radiation is constant (at all times)". Furthermore he uses the half life for carbon-14 [3]:

$$T_{½} = 5568\ yr$$

Formula 1 is used by measuring the activity A' (unit, f.ex.: $\frac{disintegrations}{s}$) and calculating the specific activity A (unit: $\frac{disintegrations}{gram\ carbon \cdot minute}$) of a carbon containing probe – and thereafter inserting it in formula 1.

To argue that the age formula is reasonable, Libby published the calibration curve (figure 1). You see that the 11 measurement circles lie near the theoretical dotted curve. The circles are provided with a vertical uncertainty line that shows the uncertainty ΔA of the activity measurement. If you measure the activity twice of the same carbon sample, you'll usually get two different results. That is due to the fact that radioactive disintegration is an accidental process (like a throw of dice).
If you measure a tree sample during the period t_1 seconds and get the number of disintegrations N_1, then A' and A can be calculated:
$A' = \frac{N_1}{t_1}$ resp. $A = \frac{A'}{m_1 \cdot 60\ s/min} = \frac{N_1}{m_1 \cdot t_1 \cdot 60\ s/\mathrm{min}}$ (the carbon sample contains m_1 gram carbon; there are 60 s on 1 min)
(N_1 is really a counting number that is *calculated* from a measured counting number N', for although you try to catch all disintegrations from the tree sample by surrounding the tree sample by Geiger-Müller-tubes, some disintegrations will not be registered in the tubes, a.o. because: Some disintegrations hit outside the tubes, some disintegrations don't have enough energy to penetrate the tubes, and a tube has a "dead period" for new disintegrations immediately after a registration. Included in the calculation of N_1 is also that the tubes measure a background radiation that isn't caused by the tree sample. This should be subtracted from the measurement of the tree sample and contributes to the uncertainty.)
Because of the statistical uncertainty of radioactive counting nubers (ΔN_1) the absolute and relative uncertainty of the specific activity A becomes:

$$\Delta A = \frac{\Delta A'}{m_1 \cdot 60\ s/min} = \frac{\Delta N_1}{m_1 \cdot t_1 \cdot 60\ s/min} = \frac{\sqrt{N_1}}{m_1 \cdot t_1 \cdot 60\ s/min}$$ resp.

$$\frac{\Delta A}{A} = \frac{\sqrt{N_1}}{N_1} = \frac{1}{\sqrt{N_1}}$$ (formula 2)

(Normally distributed counting numbers, which radioactive counting numbers are reasonably assumed to be, have the uncertainty: $\Delta N_1 = \sqrt{N_1}$.)
From formula 2 it is seen that the relative uncertainty is inversely proportional to the square root of the counting number. You should therefore count on the tree sample for a long time, so you get as high counting numbers as possible. Thereby the uncertainty of the counting number is diminshed – and in that way the uncertainty of the specific activity and the age according to formula 1.
Libby's calibration curve is based upon four carbon samples that are tree rings (tree ring, redwood), one carbon sample from Israel's history (Bible=cover from Isaiah scroll/Dead Sea scroll) and six carbon samples from Egypt history (Ptolemy, Tayinat, Sesostris III, Zoser, Sneferu, Hemaka). That tendency lasts for many years after, the calibration curve is built upon dendrochronology (= tree rings) and Egyptian chronology (= time table). Therefore I'll concentrate on these 2 chronology types.

Furthermore each of the 11 carbon samples have a *tree ring/historic uncertainty*:
1) for the three "tree ring"-samples it's put to 0 – for the "redwood"-sample it's put to plus/minus 75 years.
2) for the carbon sample from Israel's history, "Bible" (cover from Isaiah scroll/Dead Sea scroll), the historical uncertainty is put to plus/minus 100 years.

3) for the six carbon samples from Egypt history, Ptolemy, Tayinat, Sesostris III, Zoser, Sneferu, Hemaka, the historical age is put to resp. plus/minus 200 years, plus/minus 50 years, 0 years, plus/minus 75 years, plus/minus 75 years and plus/minus 200 years. These uncertainties aren’t directly uncertainties of Egyptian chronology. The historical uncertainties are due to the fact that tree samples can’t always be related to a specific year of a specific Pharaoh, but rather that you can limit it to be contemporary with or some time after a specific Pharaoh. You might also have to make assumptions of how many years have passed from a tree being felled to the wood being used for a sarcophagus or the like. As “HISTORICAL AGE (year before ab. 1952)” Libby has used the best age deduced from standard Egyptian chronology.

If you consider Libby’s curve, you might see that the vertical uncertainty lines of eight of the 11 measurements cut across the dotted curve, while three of the 11 measurements do not. That’s expected. *If measurements are normally distributed*, 2/3 are expected to be inside uncertainty and 1/3 don’t.

Counting numbers are fairly normally distributed. The prediction fits rather well, as $\frac{2}{3} \cdot 11 = 7{,}3$.

In formula 1 the age calculation is called *apparent age* to emphasize that it shall presumably be corrected to find the real age. Immediately Libby’s curve doesn’t seem to need especially big corrections – the 11 measurement circles lie near the dotted curve. You notice that e.g. the Zoser sample is different by several hundred years. (That’s not only caused by statistical uncertainty of the counting number, for the later measurement of other laboratories show some of the same results.) So a new calibration curve is needed (= a curve that shows transformation of *apparent age* to *factual age*) built upon either Egyptian chronology or dendrochronology. *What do you do if you make several calibration curves that don’t agree?*

Standard Egyptian chronology

Every Egyptian chronology is founded i.a. on Egyptian, Babylonian, Assyrian and Israeli lists of kings and written history, and archaeological findings.

In figure 2 is shown standard Egyptian chronology[4], as it appeared in 1968 and before:

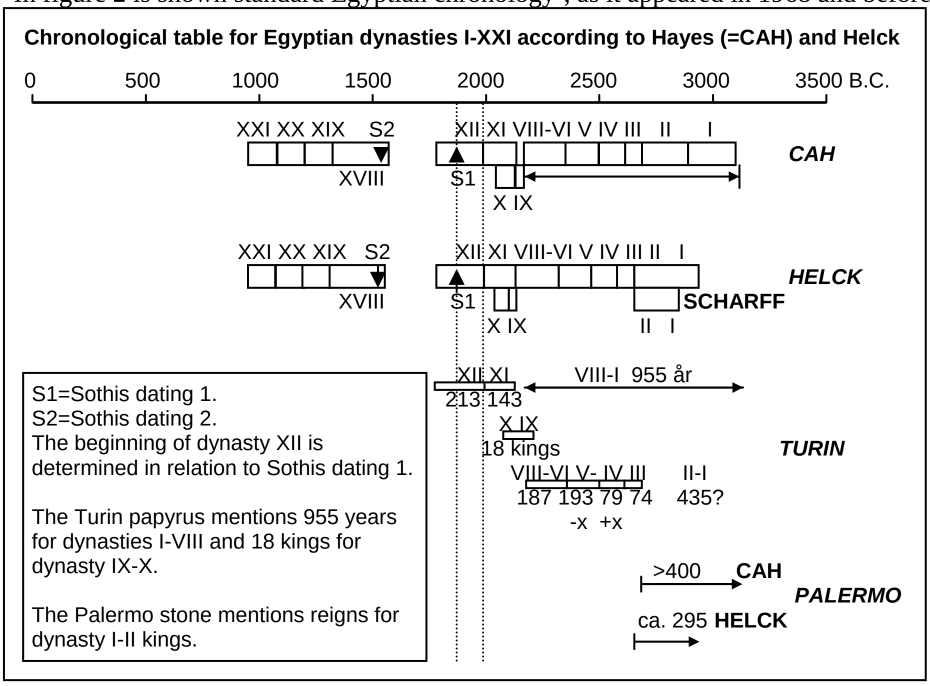

Figure 2. Standard Egypt chronology (Hayes (1962) and Helck (1968)). Reproduced after Säve-Söderbergh and Olsson (1970) [5].

The chronology is connected to our calendar by means of the 2 astronomical datings, so-called Sothis datings: S1 og S2. It’s accounts of the star Sothis’ (Sirius’) ascent on a certain calendar date according to the Egyptian calendar. Through calculations you might find which year B.C. it happened. The dating isn’t, however, without uncertainty – among other things because the interpretation of it is built on late historical sources. If the interpretation is correct, you’ve with great accuracy determined dynasty XII and XVIII in our calendar. If the interpretation is wrong, you’ll get great uncertainty into standard

Egyptian chronology. In relation to S1 dynasty I to XI are calculated from the various lists of kings and interpretation of the Turin papyrus and the Palermo stone. These interpretations aren't without uncertainty, which you might see from the fact that Hayes, Helck and Scharff don't agree. In relation to S2 dynasties XIX-XXX (not all are shown on figure 2) are calculated from the various lists of kings. Unfortunately there are many lists of kings which don't agree – so you can't get around (great) uncertainty in lengths of reigns and dynasties. More serious is the question: *Can you depend upon the succession and synchronicity/missing synchronicity of the 30 dynasties of the standard Egyptian chronology?*

Courville's Egyptian chronology

Figure 3 shows Courville's Egyptian chronology, 1970 [6]:

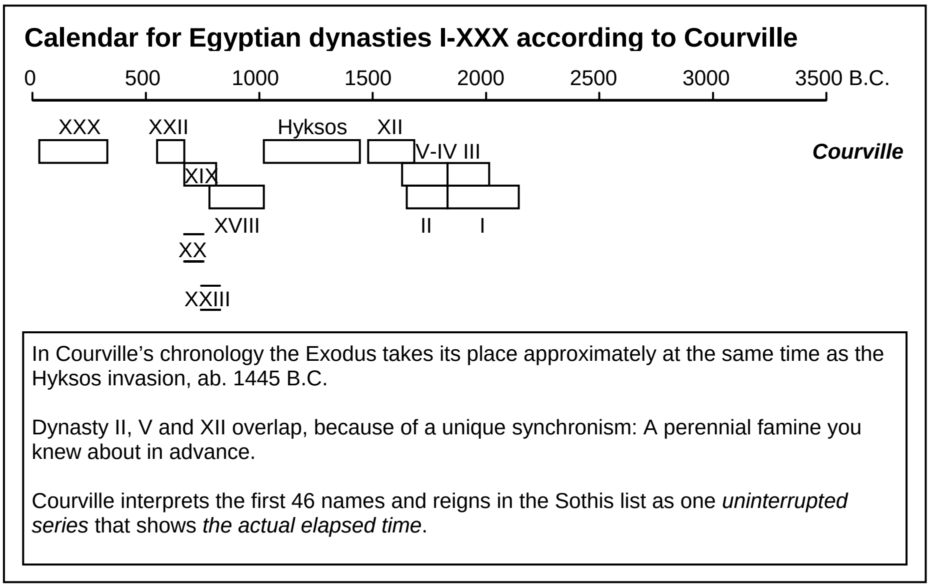

Figure 3: Courville's Egyptian chronology (reproduced from Courville, 1970 [6]).

Middle East chronologies are linked, in the sense that among other things Babylonian, Assyrian, Israeli and Egyptian written history contain synchronisms (= references to the same historical events, e.g. a battle.)
Therefore a reinterpretation of one of those will unavoidably lead to reinterpretations of the others. Apart from the written histories you can also deduce synchronisms from archaeological material.

Courville doubts the two Sothis datings so much that he does not build his chronology on them. He mentions hundreds of examples where archaeology and Israeli history *systematically* differ by several centuries – deviations that have often been blamed on Israeli written history. Since the archaeological division of periods, however, is bound up with Egyptian chronology, Courville assumes that the problem rather is caused by prevalent Egyptian chronology misplaced on the time axis – t.i. the two Sothic datings must be wrong. Without the two Sothic datings Courville of course uses all available lists of kings to build his chronology, as standard Egyptian chronology likewise does, but he weighs the sources different. Among other things he uses the interpretation of the list of kings, the Sothic List, that the first 46 names and lengths of reigns is one unbroken series that shows the actual elapsed time. (The end of the Sothic list is unfortunately corrupted with names and lengths of reigns that don't follow that system.) He thereby ends with a chronology (see figure 3) that he think gives much better accordance between archaeology and written sources – especially Israeli written history.
Example: From Israeli history you know that King Acab had an ivory palace. You find remnants of an ivory building, but in archaeological layers that according to prevalent Egyptian chronology is considered much later than King Acab – then it can't be his palace, or? I suppose so it's Acabs ivory palace, and the archeological division of periods shall be advanced that it fits? In Courville's chronology the finding fits in with Acabs reign.
(That Israeli written history is very accurate, appears from Thiele's book 1959, where he makes 396 out of 400 references to Israeli resp. Judaic reigns to agree completely. The remaining four may be miswritings? Actually the remaining four might be accurate, if you assume some hitherto unknown coregencies. With the help of Thiele's Israeli chronology you have solved a single dark point in Assyrian chronology, that's otherwise the flag ship in the Middle East with respect to accurately written year lists (the socalled eponyme lists)).

Calibration curves built upon prevalent resp. Courville's Egyptian chronologies

In the period 1949-68 there're published ab. 89 carbon-14 datings with relevance to Egypt chronology. From as many as possible of them (it's not all 89 that can be historically placed upon figure 2 resp. 3), the following correction factors for appearent age are calculated:

$$actual\ age_{common} = f_{common} \cdot appearent\ age$$

$$actual\ age_{Courville} = f_{Courville} \cdot appearent\ age$$

In the periodical Radiocarbon, where most of the 89 datings are published, you continued to calculate apperent age by means of the half life 5568 years although the half life actually was measured more accurately to 5730 years. (A correction for a half life a little wrong is only a little correction, and by continuing with 5568 in the calculations you might compare all published appearent ages.)
Which of the 2 Egypt chronologies give the most reasonable calibration curve? The question can according to my opnion not be answered uequivocally – but you might notice if there're "unreasonable" bends on the correction curves. "Unreasonable" bends might be an indication of missing /too many synchronicities of dynasties. It's far from all 30 dynasties that have published carbon-14 datings – some dynasties also have left very little archaeological materials.
The correction factors are easiest overviewed, if you instead of appearent age make a curve as function of *appearent year (B.C.)*:

$$appearent\ \ year\ (B.C.) = appearent\ age - year\ of\ \ measurement$$

Example: If the measurement is made ab. 1966 and gives the apparent age 4050 years, the appearent year (B.C.) becomes=2084.

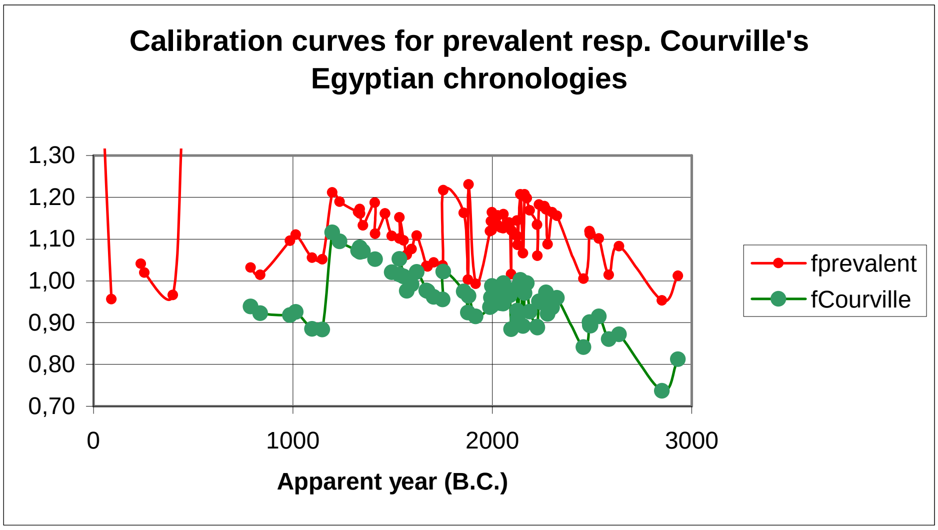

Figure 4. Calibration curves for prevalent resp. Courville's Egyptian chronologies.

The 2 curves have some small notches, among other things because there is statistical uncertainty on counting numbers. Apart from that they have some nearly linear parts that are emphasized on figure 5:

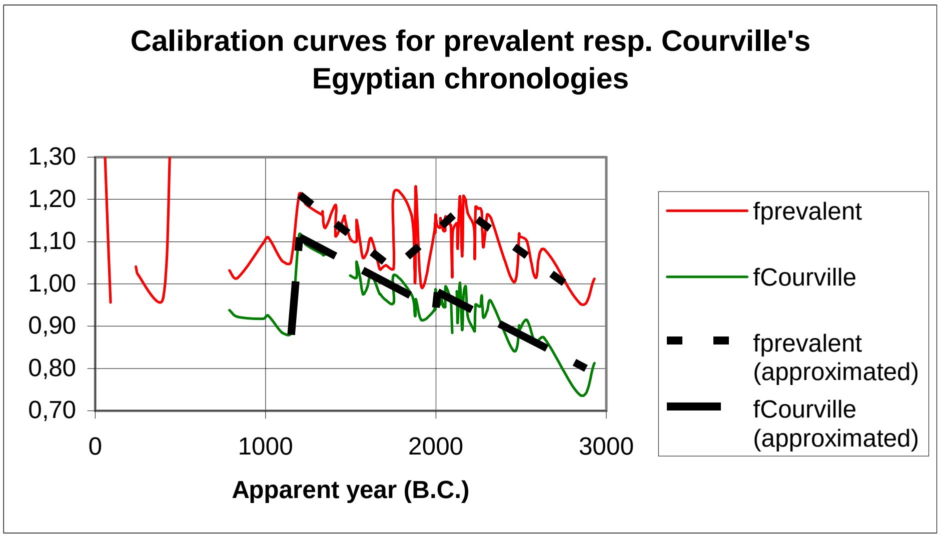

Figure 5. Calibration curves and approximated calibration curves for prevalent resp. Courville's chronologies.

Three conclusions from figure 5:

1) The approximated, common curve has a zigzag course where the middle part corresponds to appearent years ab. 1750-2150 B.C., or actual years ab. 1880-2890 B.C. The Sothis dating S1 lia at ab. 1871 B.C. If the zigzag course is considered as unreasonable, you could get a morestraight curve by advancing the Sothic dating S1. You could pose a question mark whether S1 should be interpreted that old? (You could also get a more straight curve by reinterpretation of both S1 and S2.)
2) The approximated Courville curve has a zigzag course where the 3rd part corresponds to apparent year ab. 2000-2010 B.C., or factual year ab. 1760-1930 B.C. The limit between dynasties IV-V and III respective dynasties II and I lie at ab. 1830 B.C. If the zigzag course is considered unreasonable, You could get a more straight curve by advancing this limit. You could pose a question mark whether the limit between dynasties IV-V and III respective dynasties II and I skould be interpreted that old?
3) The first part of the approximated Courville-curve has a very vertical course and corresponds to apparent year ab. 1150-1200 B.C., or factual year ab. 780-1550 B.C. However there’s a similar (albeit not as big) part with a very vertical course on the approximated prevalent curve. I’ll therefore consider it as uncertainty in the archaeological determination of some of the carbon probes.

In a later article I’ll return to these three conclusions by comparing them to conclusions made from calibration curves built upon dendrochronologies.

Litterature

[1] Finn Lykke Nielsen: *Radioaktive dateringsmetoder.* Civilingeniørspeciale. DTU, Afd. f. Elektrofysik, 1985. I: 80 s.+litteraturtillæg: 450 s.+II: 28 s.+litteraturappendix: 92 s.
[2] W. F. Libby: *Radiocarbon Dating*. The University of Chicago Press, 1952.
[3] In recent teach books are used the half life 5730 years and A_0=16.0.
[4] T. Säve-Söderbergh and I. U. Olsson. *“Radiocarbon Variations and Absolute Chronology”*. Uppsala (1970).
[5] [4], side 35-55.
[6] D. A. Courville: *“The Exodus Problem and its Ramifications”*. Challenge Books, Loma Linda, California, 1971.

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