A note on reporting radiocarbon

J. van der Plichta,b,*, A. Hoggc

aCenter for Isotope Research, Groningen University, Groningen, Netherlands
bFaculty of Archaeology, Leiden University, Leiden, Netherlands
cRadiocarbon Dating Laboratory, University of Waikato, Hamilton, New Zealand

Received 16 May 2006; received in revised form 21 July 2006; accepted 31 July 2006
Available online 18 September 2006

Abstract

Recommended reporting practice concerning 14C dates, relevant for Quaternary Geochronology, is given in this report.

Keywords: Radiocarbon; 14C; Dating; Chronology

The relative 14C content is defined as

\[ 14\delta = 14a - 1 \] (2)

which is expressed in per mill (‰) deviation from the reference. This is analogous to stable isotope practice (\(13\delta\), \(18\delta\), etc).

The reference material has a 14C activity of 13.56 dpm/gC or 0.226 Bq/gC. It is based on 95% of the value of the specific activity of the original NBS (now NIST) oxalic acid (HOx1) in the year AD 1950 (Karlen et al., 1966). A secondary oxalic acid standard (HOx2) is now in common use in most 14C laboratories. It has a defined activity ratio compared with the Ox1 standard of 1.2933 ± 0.001 (Mann, 1983).

For the stable isotope 13C, the reference is VPDB (Gonfiantini, 1984).

Mass dependent processes in nature and in the laboratory can cause isotopic fractionation. For 14C measurements, this changes the 14C content in samples producing errors in 14C ages if not corrected for. Since fractionation occurs to both 13C and 14C and because the relationship between the fractionation for 13C and 14C is known, the 13\delta value of the sample material to be dated can be used for fractionation correction.

It has become common practice to normalize 14C results for deviations of the measured 13\delta from −25‰.
The $^{14}$C activity and relative content, as defined above, therefore need to be corrected for isotopic fractionation by normalizing (subscript $N$) to $^{13}\delta_N = -25\%$:

$$14a_N = 14a \left[ 1 + \frac{^{13}\delta_N}{1 + ^{13}\delta} \right]^2 = 14a \left[ \frac{0.975}{1 + ^{13}\delta} \right]^2$$

(3)

and

$$^{14}\delta_N = 14a_N - 1.$$  

(4)

The $^{14}$C activity ratio $^{14}a$ originates from Eq. (1), where $A$ is the commonly used symbol for radioactivity expressed in Becquerel (Bq) (e.g., Friedlander et al., 1981). Recently, the symbol $F^{14}$C is advocated (Reimer et al., 2004) which is equivalent to $14a_N$. This new symbol is more “popular” and more intuitive, and therefore also followed here:

$$F^{14}$C = $^{14}a_N.$$  

(5)

Again, this symbolizes the activity ratio with respect to the standard, and includes correction for isotopic fractionation. It obviously also includes correction for background activity.

There are detailed issues involved with the relatively simple expression (3)—like the fact that the original Ox1 standard is normalized to its own $^{13}\delta$ value of $-19\%$ (Stuiver and Polach, 1977), or the fact that the value of the exponent in Eq. (3) is only approximately 2 (Mook and van der Plicht, 1999; Donahue et al., 1990). These details are usually not relevant for users of radiocarbon and are not further discussed here.

Radiocarbon or $^{14}$C ages $T$ are based on this measured and normalized $^{14}a_N$ value:

$$T = -8033 \ln (^{14}a_N) = -8033 \ln (F^{14}$C)$$

(6)

which simply follows from the exponential radioactive decay law, using a half-life value $T_{1/2} = 5568$ years:

$$T_{1/2} \ln (2) = 8033.$$  

(7)

The original half-life value as introduced by Libby (1952) is used by convention. A more accurate half-life has been measured as $5730 \pm 40$ years (Godwin, 1962).

Note that very recently the latter value has come under discussion (Broecker, 2005). But this does not influence the radiocarbon dates in BP since these are conventional.

The $^{14}$C ages thus calculated are reported in BP or “Before Present” and are termed “Conventional Radiocarbon Ages”. Summarizing, this encompasses (1) measured relative to the Ox1 standard radioactivity, (2) corrected for isotopic fractionation to $^{13}\delta = -25\%$ (3) calculated using the conventional half-life value of $T_{1/2} = 5568$ years and (4) the assumption of constancy of $^{14}$C atmospheric level during the past.

The use of the word “Present” in the unit “BP” can cause confusion because “Present” in this term corresponds to the standard activity and 1950 AD not the present day.

It is important to realize that the timescale for conventional $^{14}$C ages is defined and is referred to as $^{14}$C years (expressed in BP). This time scale needs to be calibrated in order to obtain calendar ages. This calibration procedure takes into account both the natural $^{14}$C variations and the incorrect half-life. Calibration curves are obtained by measuring the $^{14}$C content of samples, dated absolutely by an independent method—preferably absolute, such as dendrochronology. For calibration curves we refer to the most recent calibration issue of the journal Radiocarbon (vol. 46 no. 3). The present Northern Hemisphere calibration curve is IntCal04 (Reimer et al., 2004). For marine data, calibration curves need to incorporate the $^{14}$C reservoir effect; a marine calibration curve has been developed (Marine04; Hughen et al., 2004). Both curves cover the time range back to 26,000 years. Beyond 26,000, no calibration curve has been recommended thus far (Nots04; van der Plicht et al., 2004). Southern Hemisphere dates younger than 11,000 cal BP are calibrated using SHCal04 (McCormac et al., 2004). It has been recommended that Southern Hemisphere samples older than this should not be calibrated because of the uncertainties associated with the interhemispheric offset before the Holocene (McCormac et al., 2004). Calibrated $^{14}$C dates are reported in calAD or calBC (Mook, 1986). In addition, cal BP is used which means “calibrated or calendar years before 1950 AD”. Unfortunately, cal BP is also widely used for chronologies of records based on ice cores, marine cores; ESR, U-series and luminescence dates, etc. Here “Present” not necessarily corresponds to 1950. Thus, these cal BP’s are different from the $^{14}$C one, which is the only one clearly defined (i.e. with respect to 1950 AD). For this reason, the NGRIP team recently proposed the use of “b2k” (before 2000) as an alternative (Rasmussen et al., 2006). This becomes necessary because the difference between “Present” and “Present = 1950” obviously increases and is now well within the temporal resolution of the dating methods.

A special convention is needed for $^{14}$C ages close to the dating limit of 50,000 years. For $^{14}$C ages which are not so old, the measured activity plus error $^{14}$C $\pm \sigma($$^{14}$C) easily translates into an age $T + \sigma(T)$, using Eq. (6). For old samples, however, the errors in $T$ become asymmetric. In addition, activities measured as e.g. $0.01 \pm 0.10\%$ include negative values that are obviously without physical meaning. This corresponds to ages that are infinite for $^{14}$C. For this reason, the following convention has been agreed, based on the sigma value $\sigma(F^{14}$C) of the measured $^{14}$C
activity $^{14}$C (Olsson 1989):

$$\delta^1_{N} = 14^{14}$C - 1, \quad (8)$$

where

$$14^{14}$C $= 14^{14}$A $\exp \left(-\left(t_i - 1950\right)/8267\right)
= F^{14}$C $\exp \left(\text{cal BP}/8267\right), \quad (9)$$

where $T_{1/2}/\ln(2) = 8267$ for $T_{1/2} = 5730$ yr. This corresponds to $\Delta$ or $\Delta^{14}$C, which is widely used in the literature. For a full discussion on the use of the symbols we refer to Mook and van der Plicht (1999).

Thus, this shows the natural $^{14}$C content of a sample, as compared with 1950.

Finally, we note that the definitions given here are valid for all existing $^{14}$C-dating techniques, once fractionation normalization is corrected for. They apply to conventional radiometry (both liquid scintillation spectrometry, LSC and proportional gas counting, PGC) and mass spectrometry (accelerator mass spectrometry, AMS).

For detailed examples and special cases, such as $^{14}$C in the hydrological cycle and dosimetry, we refer to Mook and van der Plicht (1999).

References


