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Abstract:

Radiocarbon dating can be used to determine the age of objects that contain components that were once alive. In the case of human remains, a radiocarbon date can distinguish between a crime scene and an archeological site. Documents, museum artifacts and art objects can be dated to determine if their age is correct for the historical context. A radiocarbon date does not confirm authenticity, but it can help identify a forgery.

Keywords: Carbon-14, C-14, radiocarbon dating, isotope dating

INTRODUCTION

Radiocarbon dating is traditionally considered an archeological tool rather than a forensic one. Radiocarbon or carbon-14 (^{14}C) is produced naturally in the atmosphere by cosmic ray interactions with nitrogen. Single carbon atoms in the atmosphere are chemically reactive and are quickly oxidized to carbon dioxide CO_2. The CO_2 from the atmosphere is incorporated into plants and works its way up the food chain to label every living thing with ^{14}C. The natural atmospheric concentration of natural ^{14}C with respect to all carbon has remained relatively stable at about 1.2 parts per trillion over the past several thousand years with the exception of the radiocarbon bomb-pulse over the past half-century (See Carbon-14 Bomb-Pulse Dating). With a radioactive half-life of 5730 years, the radioactive decay of ^{14}C is minimal within the time periods of interest in most medical forensic cases and applicable for samples over 300 years of age. Willard Libby was awarded the Nobel Prize in Chemistry in 1960 for the development of radiocarbon dating [1].

BASICS OF RADIOCARBON DATING

Radiocarbon dating relates the ^{14}C /C ratio in a sample to an extensive historical record to determine the age of a sample. The rate of radioactive decay of ^{14}C is relative slow and predictable, so the concentration of ^{14}C changes slowly and reliably over time once a biological material dies and stops incorporating new carbon into its structure. The decrease in ^{14}C/C concentration from the contemporary value is used to determine the age of the sample. The natural production of ^{14}C does vary a bit over time. Extensive geological and archeological records are used to account for the variations in atmospheric ^{14}C concentration over the chronological range of radiocarbon dating (300-50,000 years before present) [2,3]. Any sample greater than 50,000 years old has too little ^{14}C to measure accurately. There is some debate over the accuracy of the ^{14}C calibration between 40,000 and 50,000 years before present, but it is hard to conceive of a forensic sample of this age. Fossil carbon, either coal or petroleum, is older than 60,000 years and free of ^{14}C.

MEASUREMENT OF RADIOCARBON SAMPLES

Today most ^{14}C dating analyses are conducted using accelerator mass spectrometry (AMS), although some labs still use decay counting. AMS is much faster and generally more precise than decay counting since it measures differences in carbon atom mass and is not constrained to wait for atomic decay. AMS can also use smaller samples than decay counting, an important issue when analyzing evidence. There are about 100 AMS facilities world-wide.

Sample preparation and measurement details vary among AMS facilities, depending on the type of sample to be analyzed and the design of spectrometer. Routine radiocarbon analyses using accelerator mass spectrometry (AMS) are performed on samples containing about 1 milligram carbon. Samples as small as 50 μg carbon can be analyzed at some labs, but measurement uncertainties are larger. Nearly all AMS facilities that perform high precision dating follow these general procedures to minimize contamination from outside sources of carbon and reduce measurement backgrounds. Samples are dried completely and then combusted with excess oxygen to produce CO_2. The CO_2 is purified to remove water vapor, nitrogen, oxides of nitrogen, and oxides of sulphur. It is then reduced to graphite or elemental carbon on metal catalyst, often cobalt or iron powder.

Primary standards, secondary standards, and backgrounds are similarly processed to produce graphite, which is form of carbon analyzed by the majority of AMS systems. Graphite is the preferred form of carbon because it can be made easily at high purity, produces intense negative ion currents, and can be prepared at satellite labs and shipped to AMS facilities for analysis. A handful of gas accepting ion sources that take direct feed of CO_2 exist, but they are not typically used for high precision dating. It is important to have consistent sample source material (e.g., all carbon graphite) because different molecules ionize with different efficiencies. Methods for producing graphite for elevated biological tracing experiments are generally unsuitable for radiocarbon dating due to larger sample-to-sample variation and higher background [4,5].

The precision of radiocarbon dating depends on the ability to measure the ^{14}C concentration in a sample and the shape of the calibration curve. It is relatively easy to achieve 0.5-0.8% precision when analyzing relatively young full-sized samples. This measurement precision translates to a chronological uncertainty of ± 30-60 years in most samples less than 10,000 years old. Samples more than 25,000 years old can still be measured to 1% precision, but uncertainty propagation from backgrounds and the calibration curve typically yields uncertainties greater than ± 100 years. The conventions for reporting radiocarbon dates are described by Stuiver and Polach [6].

SAMPLES AMENABLE TO DATING

Anything that was alive in the past is amenable to radiocarbon dating. Charcoal, wood, straw, hair, cloth, and bones are often dated in archeological sites. Historical documents and works of art are also routinely dated to confirm that the paper or canvas is of the appropriate age for the object.

Bone

Bone is the preferred sample matrix for dating human remains. Bone's ability to resist decay while containing a relatively high concentration of carbon makes it a desirable material for traditional dating. The carbon in collagen does turnover slowly while a person is alive, so the ^{14}C content is really a lifetime average rather than a snapshot in time. Traditional bone dating uses a collagen extraction to avoid potential complications with mineral exchange of carbonates in bone in the environment. Collagen is a protein and is not affected by environmental carbonate exchange like the mineral component of bone.

Specific procedures for collagen extraction vary slightly among labs. In general, the mineral component of bone is dissolved in acid to free the collagen into solution. A variety of washing, rinsing and filtering techniques are then applied to purify the collagen. Once purified, it can be combusted like any organic sample.

If human remains are found without any other evidence, radiocarbon analysis of bone collagen or hair can determine whether authorities have a crime scene (see Carbon-14 Bomb Pulse Dating) or an archeological site. If the ^{14}C content of the collagen is elevated above the level in 1950, the person died sometime after 1955. The decrease in ^{14}C concentration due to decay can be measured over a 100 years, but the small differences in natural production between 1650-1955 and the decay combine to it very difficult to separate samples chronologically over this time. Collagen from before 1650 can be clearly distinguished.

In the United States a ^{14}C date can determine ownership of remains or precipitate a court battle over ownership, such as the case of Kennewick Man [7-10]. The Native American Graves Protection and Repatriation Act (NAGPRA) requires institutions that receive U.S. federal funding to return of human remains and sacred artifacts to ethnic descendents when they are available.

Documents and art objects

Radiocarbon dating of documents and art objects is routinely done by museums to confirm the items age is consistent with its providence. This approach only confirms paper, cloth or canvas is the appropriate age, it does not confirm authenticity. A radiocarbon analysis that contains recent bomb pulse carbon identifies a forgery of an older item.

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