Supplementary Material

Figure 1. Time line of development of radiocarbon dating method. Essential for the RD was the discovery of Radiocarbon[1] work by Libby and colleagues[2-6] leading to establishment of the method. The following developments: discovery of Suess effect[7], development of the accelerator mass spectrometry[8-10], development and updates the calibration curve [11-15]

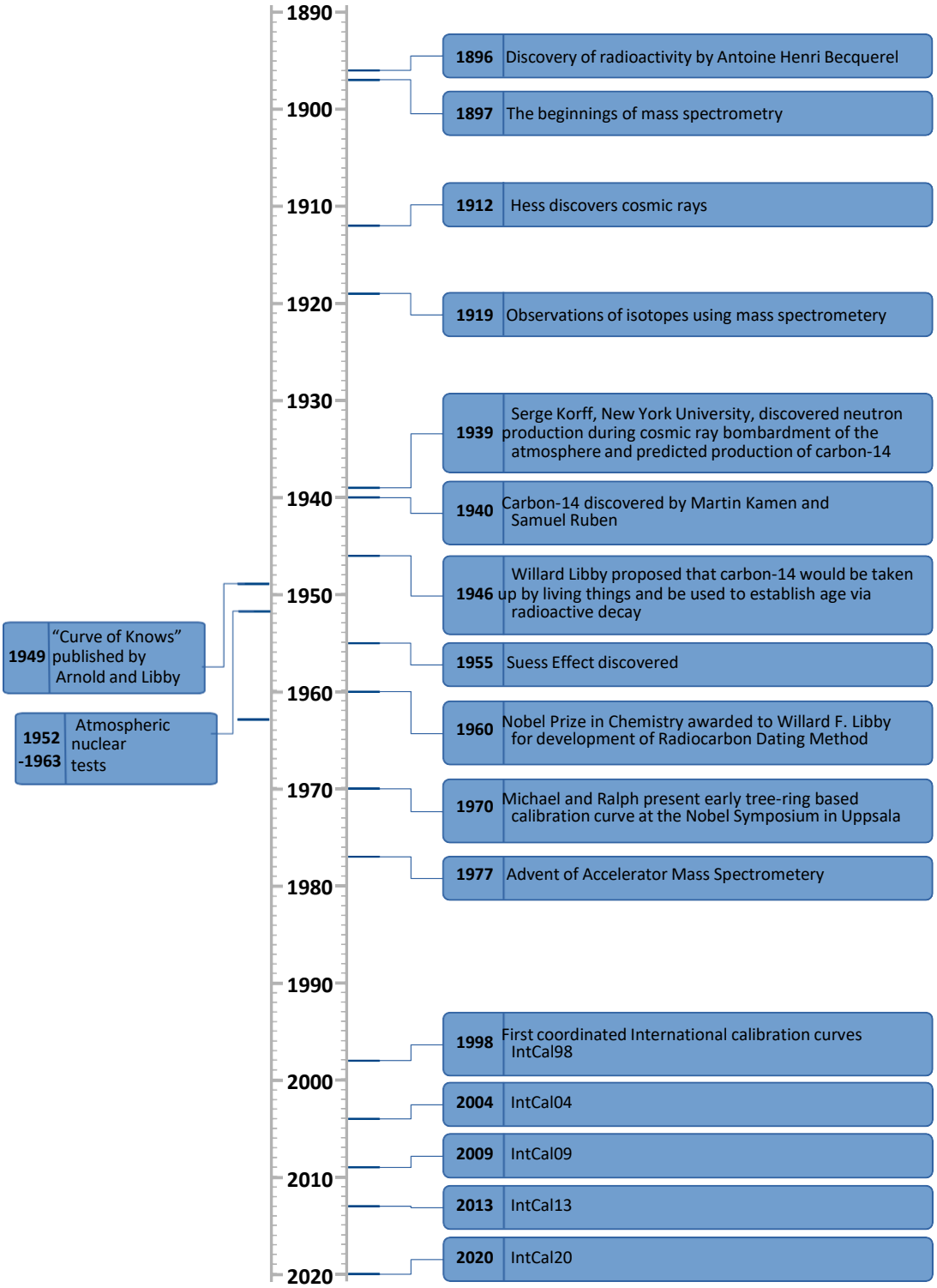

Table1. History of measurements of ^{14}C half-life based on a summary by Kutschera[16,17]

Year	Reported $T_{1/2}$ (a)	Research team/Publication	Comments
1941	10^3 -10^5	Ruben and Kamen[18]	Discovery of radiocarbon
1946	4700±470 5300±800	Reid et al.,[19] Norris and Inghram[20]	
1949	5589±75	Jones[21]	
1949	5720±47	Engelkemeir et al.,[22]	Applied by Arnold and Libby for publications of 'Curve of Knowns'
1950	5580±45	Engelkemeir and Libby[23]	Previous 5720±47 value after additional corrections for gas counter
1950	5513±165	Miller[24]	
1952	**5568±30**	Libby[25] proposed the value which became 'Libby half-life'	Weighted mean of 5589±75, 5580±45, 5513±165
1961	5760±60	Mann[26]	
1961	5780±65	Watt et al.,[27]	
1962	5680±40	Olsson et al.,[28]	
1962	5730±40	Godwin 1962[29] 'Cambridge half-life'	Fifth Radiocarbon conference[30] accepted weighted mean of 3 values: 5760±60, 5780±65, 5680±40
1968	5660±40	Bella et al.,[31]	
2013 **2019**	**5700±30**	Kutschera[16] Kutschera[17]	weighted mean of 4 values: 5760±60, 5780±65, 5680±40, 5660±40
	5700±30	Nuclear Data Center Brookhaven National Laboratory	Currently accepted value NuDat2

Table 2. Overview of applications (by carbon reservoirs) with related material with requirements for sample size and other information given in references.
G: Graphite; GIS: Gas Ion Source
Dry mass given in 'Amount (mg) equivalent to 1 mg C' is an estimate for an optimal graphite sample of 1 mg of C for G. From this number following can be estimated:

- Amount is rather a range dependent on purity and preservation (for example hidden sand & dirt makes wood and charcoal heavier)
- minimum for G:
  - dependent on the laboratory
  - µG: some laboratories graphitize as small as 10 µg[32]
- Sample for GIS*: optimal 50 µg C, minimum 10 µg
- *special analysis, usually part of collaboration, contact the lab

Carbon source	Application	Sample Material	Selected datable fraction	Amount (mg) equivalent to 1 mg C	Additional Info
Terrestrial					
Fossil trees including charred wood and anthropogenic wood products	^{14}C Calibration[13,33], Archaeology[34-36], Climate research[37], Solar activity[38,39], History of architecture[40], Ecology, Landscape morphology[41], volcanology[42-44], Cultural heritage[45-48]	Wood and charcoal	1) charcoal &whole wood ABA 2) cellulose	1) 5-10 2) 10-30	1) Waterlogged wood has poor cellulose preservation [49] 2) Wiggle matching: Improved calendar age precision (Bayesian) for Sequence of tree rings (30-70) Multiple samples with gaps # tree rings 3) avoid wood or charcoal with roots
Living trees	^{14}C calibration[50,51], Ecology and ancient trees[52-67], tree rings[68-70], Climate[39], Geology, anthropogenic environmental changes[71,72]	wood	1) Whole wood ABA 2) cellulose	1) 5-10 2) 10-30	Wiggle matching possible (see above)
Peat	Climate research[73,74], Geology[75], Ecology, Archaeology, carbon storage	Decomposed organic matter, preserved plant remains	1) Fine fraction of bulk (<150µ): humin and humic acid[76] 2) identifiable fragments of plants[77,78]	1) 10-20 2) 5-10	1) Avoid roots by sieving (modern contamination)[75]

Sedimentary records: fluvial, caves, lake deposits, soils, permafrost, loess, paleo soils,	^{14}C calibration[79], Climate research, Geology, archeology, anthropogenic environmental changes[80], ecology[81], food webs[82], carbon storage[83]	Bulk sediment, Organic matter, macrofossils, Soil mesofauna	1) Fine fraction of bulk (<150µ) : humin and humic acid[76] 2) identifiable fragments of plants[77] 3) biomarkers 4) Earthworms droppings [84,85] 5) mesofauna[82]	1) dependent %C 50—500 2) 5-10 3) grams of sediment 4) 8-10 5) 0.5-5	Avoid roots by sieving[75] Separation of compounds for CSRD specific to the desired compound
Remains of plants and animals	Ecology[86-88], Climate research, archaeology[89-91] anthropogenic environmental changes	Bulk sediments	1) fragments of plants[77] 2) insects[92,93] 3) pollen[94-98] 4) animal bones[99,100]	1-2) 5-10 3) > 0.1 (GIS or µG)	2) CSRD of insects [48,92,93] 3) Separation of pollen [94-98]
Tufa (fresh water carbonate)	Climate research[101,102], archeology[103]	carbonates	1) $CaCO_3$ 2) Organic inclusions	1) 8-10 1a) LA AMS [104,105] 2) >0.1 (GIS or µG)	1) LA AMS direct ^{14}C analysis [104,105] Dependent of purity of carbonate more material required
Speleothems	^{14}C calibration[106,107], Climate research, geology, ecology, anthropogenic environmental changes[108,109], Archeology (?),	carbonates	1) $CaCO_3$ 2) Organic inclusions	1) 8-10 1a) LA AMS [104,105] 2) >0.1 mg	1) LA AMS direct 14C analysis [104,105] Dependent of purity of carbonate more material required DCF correction required Stable isotopes
Fresh water	Hydrology[110,111], Climate research, Ecology[112], anthropogenic environmental changes[113]	Groundwater River, Streams and lake water, Peat porewater[114]	1) DIC 2) DOC[115] 3) DOM[114] 4) POM? 5) Stygofauna[112]	1) 60 ml 5) >0.1 (GIS or µG)	
Atmospheric Air gas emissions (soils, permafrost)	Bomb Peak calibration, anthropogenic environmental changes[116], microbial activities[117], mineralization of soil organic carbon[118]	air	1) CO_2[117] 2) methane CH_4[116,119]		

Aerosols	anthropogenic environmental changes	aerosol	Filters		
Glaciers/permafrost	Climate change, anthropogenic environmental changes	ice	Organic matter	>0.1 (GIS or µG)	
Marine					**Reservoir Age Correction** [120]
Sedimentary records	Climate research, ecology, anthropogenic environmental changes, radiocarbon calibration[121]	Bulk sediment	1) Foraminifera 2) biomarkers	1) 8-10 2) grams of sediment	Separation of compounds for CSRD specific to the desired compound
Corals	^{14}C calibration, Climate research, ecology, anthropogenic environmental changes, reservoir age reconstruction[122]	carbonates	1) $CaCO_3$ 2) Organic inclusions	1) 1) 8-10 1a) LA AMS [104,105] 2) >0.1 (GIS or µG)	1) LA AMS direct ^{14}C analysis [104,105]
Fish, Mollusk	ecology[123-125], anthropogenic environmental changes, reservoir age reconstruction	carbonate	$CaCO_3$	1) 8-10 1a) LA AMS [104,105] 2) >0.1 (GIS)	1) LA AMS direct ^{14}C analysis [104,105]
Ocean water	Ocean circulation, anthropogenic environmental changes	water	1) DIC 2) DOC[126] 3) POM	1) 60 ml[127] 2) 1-1.5 l[128,129] 3) 1-2 l[129]	
Stromatolites	Ecology, environmental changes[130], reservoir age reconstruction	carbonate	$CaCO_3$	1) 1) 8-10 1a) LA AMS [104,105] 2) >0.1 (GIS)	1) LA AMS direct ^{14}C analysis [104,105]
Human history and collections of Flora and Fauna					
Human tissue	biomedical, forensics	Various tissues and cells	1) Bones and teeth 2) Soft tissue, hair, lipids 3) DNA*	1) 200-1000 2) 5-10 3) >0.01(GIS or µG)	3)* special consideration for DNA sampling see BOX 5
Human remains	Archaeology[131,132], Genetics, medical history, forensics[133]		1) skin, hair 2) Bones 3) Cremated bones	1) 5-10 2) 200-1000 3) 500	2) sample amount dependent on bone preservation

pottery	Archaeology, diet	Organic remains	1) Whole bulk 2) biomarkers[134]	1) 5-10 2) >0.1 (GIS or µG)	Separation of compounds for CSRD specific to the desired compound
Short lived charred and fresh vegetal material	Archaeology	Plant remains	1) straw 2) grains, seeds 3) pits 4) nuts	1-4) 5-10	
Collections of seeds, herbaria, museum collections of specimens	Archaeology, Cultural Heritage, Genetics, Ecology, Climate, anthropogenic environmental changes	Plant and animal remains	1) vegetal fragments/tissue 2) bones 3) other tissue: hair, skin	1) 5-10 2) 200—1000 3) 5-10	Potential conservation and contamination 2) sample amount dependent on bone preservation (
Anthropogenic products					
Buildings and constructions	Archaeology, cultural heritage, history of architecture	Organic and inorganic carbon	1) Wood 2) Charcoal 3) Vegetal temper 4) mortar	1) 5-10 4) milligrams to grams	4) mortar sample specific
Art and written documents	Rock Art[135-137], Archaeology, cultural heritage, history of architecture, art history[138,139], forensics	Organic and inorganic carbon	1) Wood 2) textiles 3) paper 4) papyri 5) parchment 6) binder 7) pigments[138] 8) corals and pearls (carbonates)	1-5) 5-10 8) 3-8	6-7) pigments and binder sample specific
Industrial and luxury Products: biofuels, bio plastic, food, perfumes, pharmaceutical, clothing	Forensics, wild life protection[88,140]	Organic and inorganic carbon		1) 5-10 mg 2) 0.5-1 g	1) AMS 2) Conventional counting technique

Table 3. Thematic databases compiling regional data or thematic data

Name	Region/Subject	Database
IntCal	Calibration curve	http://intcal.org/
New Zealand Radiocarbon Database	NZ	https://www.waikato.ac.nz/nzcd/
Archaeology Data Service	UK/Archeology	https://archaeologydataservice.ac.uk/archsearch/
CARD[141,142]	Canada/Archeology	https://www.canadianarchaeology.ca/
The 14SEA Project	Southeast Europe and Anatolia/Archeology	http://www.14sea.org/index.html
Radiocarbon Palaeolithic Europe Database[143]	Europe/Archeology and Climate Change	https://ees.kuleuven.be/geography/projects/14c-palaeolithic/index.html
Louisiana Division of Archaeology Carbon-14 Database	Archeology	https://www.crt.state.la.us/cultural-development/archaeology/crm/databases/louisiana-radiocarbon-database/index#howto
Southern African 14C Database SARD[144]	Africa/Archeology	https://c14.arch.ox.ac.uk/sadb/db
ISRad[145]	Soils	https://soilradiocarbon.org/
MOSAIC[146]	Modern Ocean Sediment	http://mosaic.ethz.ch/
The Kentucky, Ohio and West Virginia Radiocarbon Database	Archeology	http://crai-ky.com/kentucky-ohio-west-virginia-radiocarbon-database/
Mesoamerican Radiocarbon Database (MesoRad)	Mesoamerica/Archeology	https://www.mesorad.com/
Scottish Radiocarbon Database	Scottland	https://canmore.org.uk/project/919374
OASIS	Archeology, Diet	https://www.oasisnorth.org/about-databases.html
A cal 14-C late quaternary eruption database[147]	Volcanic Eruptions	http://www.electronic-earth-discuss.net/1/123/2006/eed-1-123-2006-print.pdf

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