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Dr F G McCormac[1], M Thompson[2] and D Brown[3]

Summary

In February 1998 English Heritage provided a grant for two small-sample high-precision counters to extend the capacity for this sort of radiocarbon measurement at the Queen's University, Belfast Radiocarbon Laboratory. This report explains the processes used for liquid scintillation counter characterisation, optimisation, and benzene purity correction and provides details of background, oxalic acid standard, and known-age wood measurements. The counters are now operational.

Keywords

Radiocarbon

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CHARACTERISATION, OPTIMISATION, AND STANDARD MEASUREMENTS FOR TWO SMALL-SAMPLE HIGH-PRECISION RADIOCARBON COUNTERS

Introduction

At the end of 1996, a new system for small-sample high-precision radiocarbon dating became available to commercial collaborators at the Queen′ s University, Belfast Radiocarbon dating Laboratory. This followed the successful completion of an NERC Research Grant (GR/H26055).

In order to expand the capacity for this new dating method to meet the demand of projects funded by English Heritage, an infrastructure grant for two new liquid scintillation counters was agreed.

This report describes the processes and measurements carried out to commission this equipment for small-sample high-precision radiocarbon measurement.

Installation

Two Quantulus 1220 liquid scintillation counters were purchased from EG&G Wallac Ltd who delivered, installed, and commissioned them between 13 May 1998 and 20 May 1998. Both counters were modified as requested by the Belfast Radiocarbon Laboratory, to have manual high voltage adjustment in line with all the existing Quantulus counters in the laboratory. Both counters have been installed in a purpose built, shielded basement laboratory in the Palaeoecology Centre at Queen's University, Belfast. They are now designated as Q5 and Q6.

Vial characterisation and background measurements

In setting up a counter for high precision measurement all possible sources of variability of the ^{14}C count rate need to be minimised. For this reason 200 low-potassium glass vials were weighed, and a catalogue of vial weights was produced (see Appendix 1). One of the set was broken and discarded. Each vial was examined for optical quality and uniformity of glass and a further 23 vials were discarded. Of the remaining 176 vials, two sets of 10 with the smallest weight range were selected as counting vials, ie the variance in total glass weight for the vial set was minimised (see Appendix 2). Chrome-plated brass caps were selected to fit these vials. The sealing and vial filling technique are as described in Pearson (1983).

Each of the 10 vials for each counter was filled with 2.6265g of analar benzene (ie no ^{14}C) and 0.05g of butyl PBD. The background activity of the vials was measured across a range of channel intervals (Tables 1 and 2). The average counts per minute for all 20 vials were determined and the six closest to the mean in each counter were selected for use. This is a lengthy process and was begun before the counters were optimised. Background counts per minute (CPM) are shown for channels 200-600 and the final counting window used, ie, Q5 channel 108-568 and Q6 channel 104-568. Tables 1 and 2 shows the vials selected as the initial set (others are retained and used when breakage occurs). In addition, weight loss due to evaporation over the four months counting time was determined (Tables 3a-b show weight loss data for each vial). The selected vials fell within accepted limits for weight loss ($<$ 0.0003 g per day). On only one occasion was weight loss actually used as a selection parameter.

Oxalic acid II standards

Twelve samples of oxalic acid II (NBS 19) were converted to carbon dioxide by wet oxidation and synthesised to benzene according to methods outlined in Wilson *et al* (1996). Each was counted in one of the selected vials. The average counts per minute per gram of benzene, after background subtraction, $\delta^{13}C$ fractionation correction, correction for ^{14}C contamination during synthesis, and correction to the AD 1890 atmospheric ^{14}C level (Stuiver and Polach 1977), are given in Tables 4 and 5. These samples provide an indication of the vial to vial variability for samples standards because the benzene was synthesised as a homogenised batch.
The six oxalic acid samples for each counter, each measured in a different vial, verify the reproducibility from a single known-activity standard. In addition they, along with four additional oxalics prepared independently for each counter, provide a basis for future oxalic acid determinations for dating samples of unknown age.

Counter characterisation and optimisation

Sets of high voltage measurements were made on the counters when the automatic high voltage option was used. The results are given in Appendix 3. The measurements were so stable that the possibility of automatic control of high voltage was considered. The requirement of small-sample high-precision measurement, to keep overall counting times as small as possible and precision as high as possible, placed a premium on maximising count rate. For this reason a series of tests was run to determine if open window counting and automatic high voltage control could be used. An example of the results of the tests are given in Appendix 4. Calculations were made based on the balance point window described in McCormac (1992) and using a fully open window. The effect on date determination was shown to be negligible. This experiment confirmed the viability of automatic control and open window configuration. These settings have been used for configuration of the instruments.

Precise determination of error multipliers requires a considerable quantity of data. Preliminary analysis suggested that the multiplier for the system lay between 1 and 1.25. A conservative value of 1.25 was used in initial calculations. Further measurements (Tables 6a-b which give error multipliers of 1.21 and 1.04 for Q5 and Q6 respectively) have shown that this is indeed conservative. However, because of problems encountered with Q5 we have continued to use 1.25 and all results given in this report use this value.

Dendrochronology

Sixteen 100g samples of oak (*Quercus patrea* and *Quercus rubra*) from the decades centered at AD 725 to AD 575 were supplied to the Belfast Radiocarbon Laboratory on the 18 - 19 January 1999. The samples were mainly extracted from one wood sample Q3693. Four radiocarbon samples centering on AD 605, AD 595, AD 585, and AD 575 had some wood from sample Q3685. The wood was obtained from structural timbers of a horizontal mill from the townland of Brabstown, Co Kilkenny, Ireland. The location of this site is at latitude 52° 40' N and longitude 7° 24' W. Sample Q3693 is from the cross-piece of the mill while sample Q3685 is from a collapsed upright. These tree-ring series from these two samples are a part of the Brabstown master chronology which is 333 years in length and dates from AD 549 to AD 881. This chronology gives extremely significant consistent correlation values with a series of local and national chronologies.

Dendrochronological methodology

Tree-ring dating for this site was carried out using the methodology described by Baillie (1982). The samples have been prepared by polishing the surface with various grades of emery paper. The tree-ring pattern is then highlighted with teaching chalk. This is rubbed into the polished surface of the sample. The spring and summer pores retain the chalk and provide better visual definition of the ring widths under the microscope.

Measurement of the tree-ring pattern was carried out using a Henson measuring stage. This machine measures the annual ring width in 1/50mm. The tree-ring series obtained from the samples was plotted on graph paper for visual comparison by a dendrochronologist. The correlation values in Table 7 were obtained by using the tree-ring cross-dating program called Cross84 (Munro 1984). Extremely significant and consistent correlation values were obtained for samples Q3693 and Q3865.

Brabstown tree-ring chronology

A mean master chronology was formed using the samples listed in Table 7. This chronology is 333 years in length. It was then compared with a series of site chronologies from the southern part of Ireland. Extremely significant and consistent correlation values were found. These results are listed in Table 8. These results indicate that the Brabstown chronology dates from AD 549 to AD 881. A comparison was made with a tree-ring chronology called the North Mills Index Master (Nthmills). This is an independent chronology from the northern part of Ireland. The Brabstown chronology gave an extremely significant and consistent correlation value ($t = 5.72$***) with this chronology.

Known-age wood standards

Each decadal sample was pre-treated to alpha cellulose (Hoper *et al* 1998). The samples were then divided into two parts and combusted, synthesised to benzene, and counted independently. The results are given in Table 9 and are plotted with respect to Pearson *et al*

(1986) in Figure 1, Pearson *et al* (1986) (decadal replicates combined and averaged) in Figure 2, INTCAL98 Stuiver *et al* (1998a) in Figure 3, and The University of Washington decadal measurements on north American conifers Stuiver *et al* (1998b) in Figure 4. Table 10 gives the offsets of the measurements we have made on decadal oak with respect to these datasets. The offset with respect to the Pearson *et al* (1986) calibration data set is –3.8 ± 7.6 yrs. With respect to INTCAL98 the offset is –16.1 ± 6.2 radiocarbon years, and between the replicates of decadal oak measured in the series it is 1.4 ± 8.7 yrs.

Conclusions

The two counters funded by English Heritage have been installed and commissioned at the Queen's University, Belfast Radiocarbon Laboratory. Sets of vials have been prepared, and standard and background data accumulated. Replicate pairs of decadal samples of oak (Figures 1 – 4) show the excellent agreement of measurements made on the system with previous calibration data and highlight the need to create bespoke segments of calibration for the resolution of chronological problems in difficult time periods such as that of Anglo-Saxon England.

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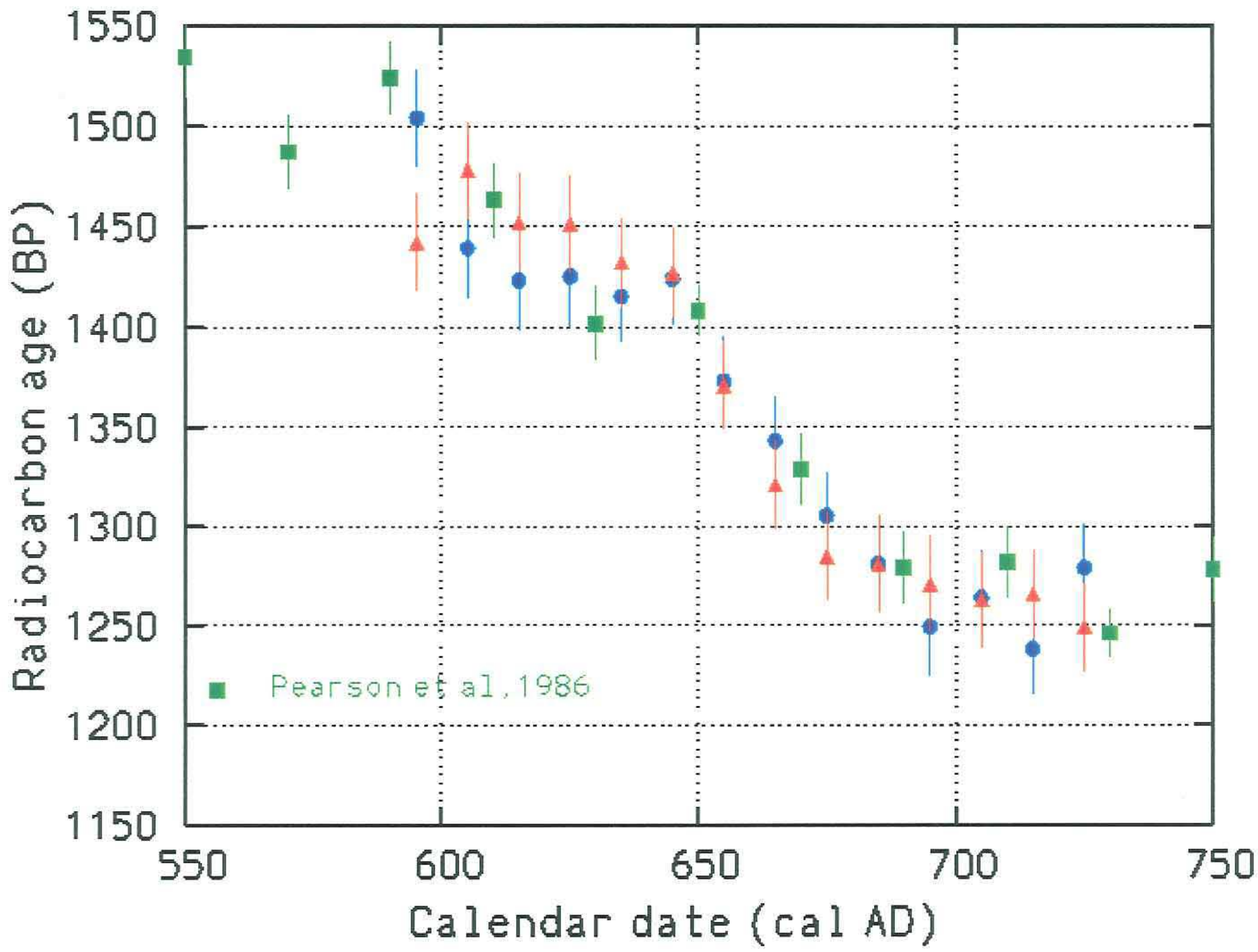


Figure 1. Brabstown decadal replicates plotted with respect to Pearson *et al* (1986)

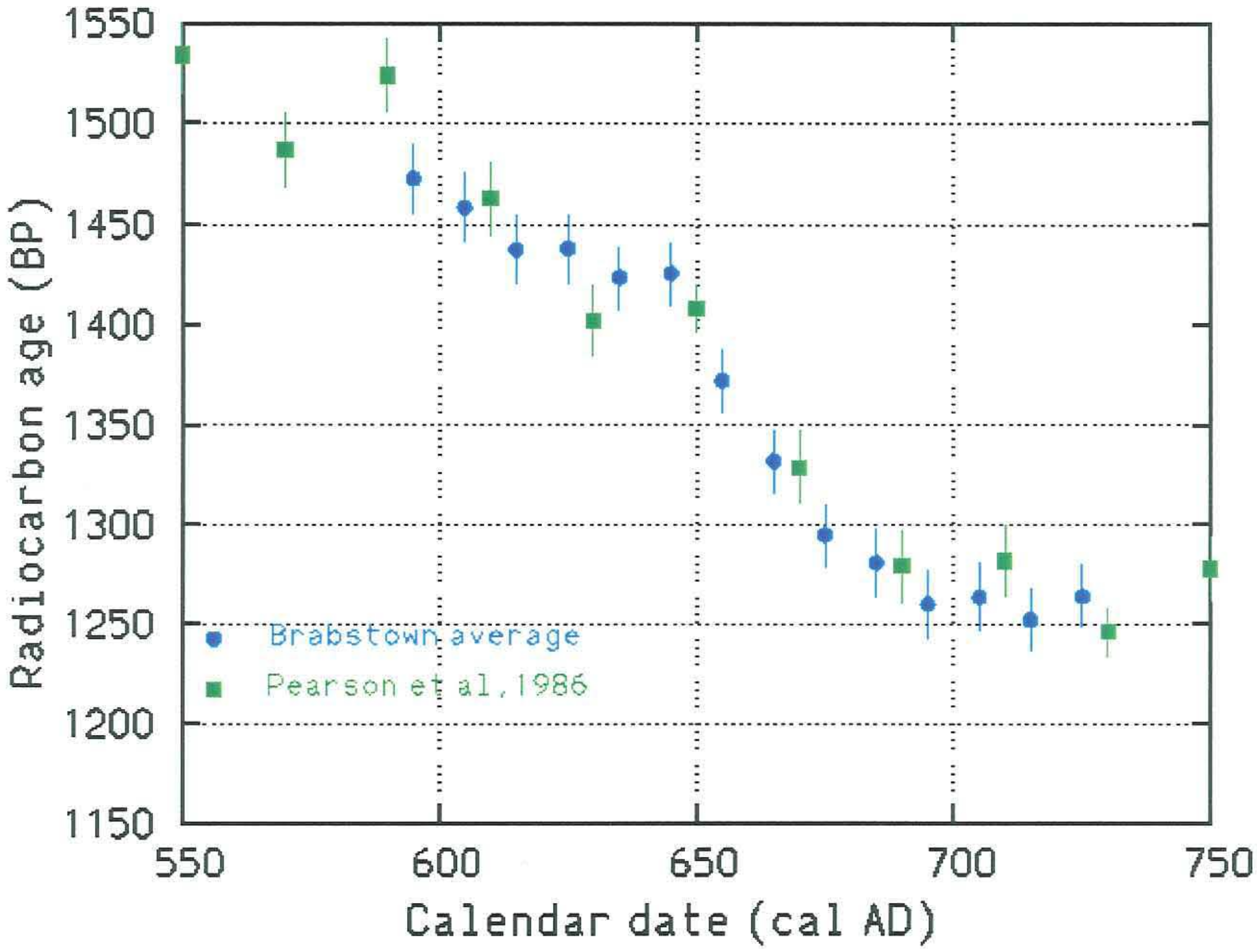


Figure 2. Weighted averages of Brabstown decadal replicates plotted with respect to Pearson *et al* (1986)

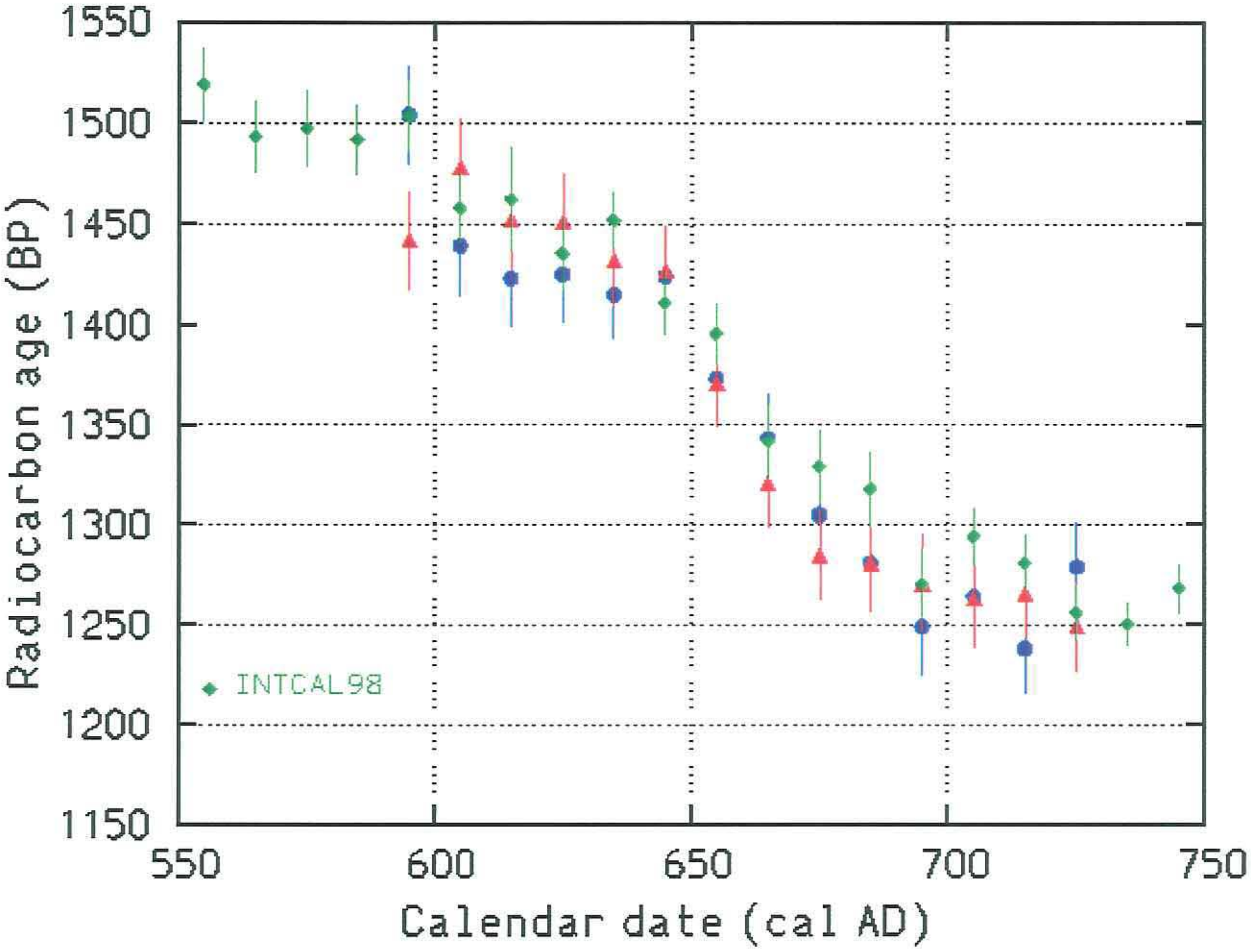


Figure 3. Brabstown decadal replicates plotted with respect to INTCAL98 (Stuiver *et al* 1998a)

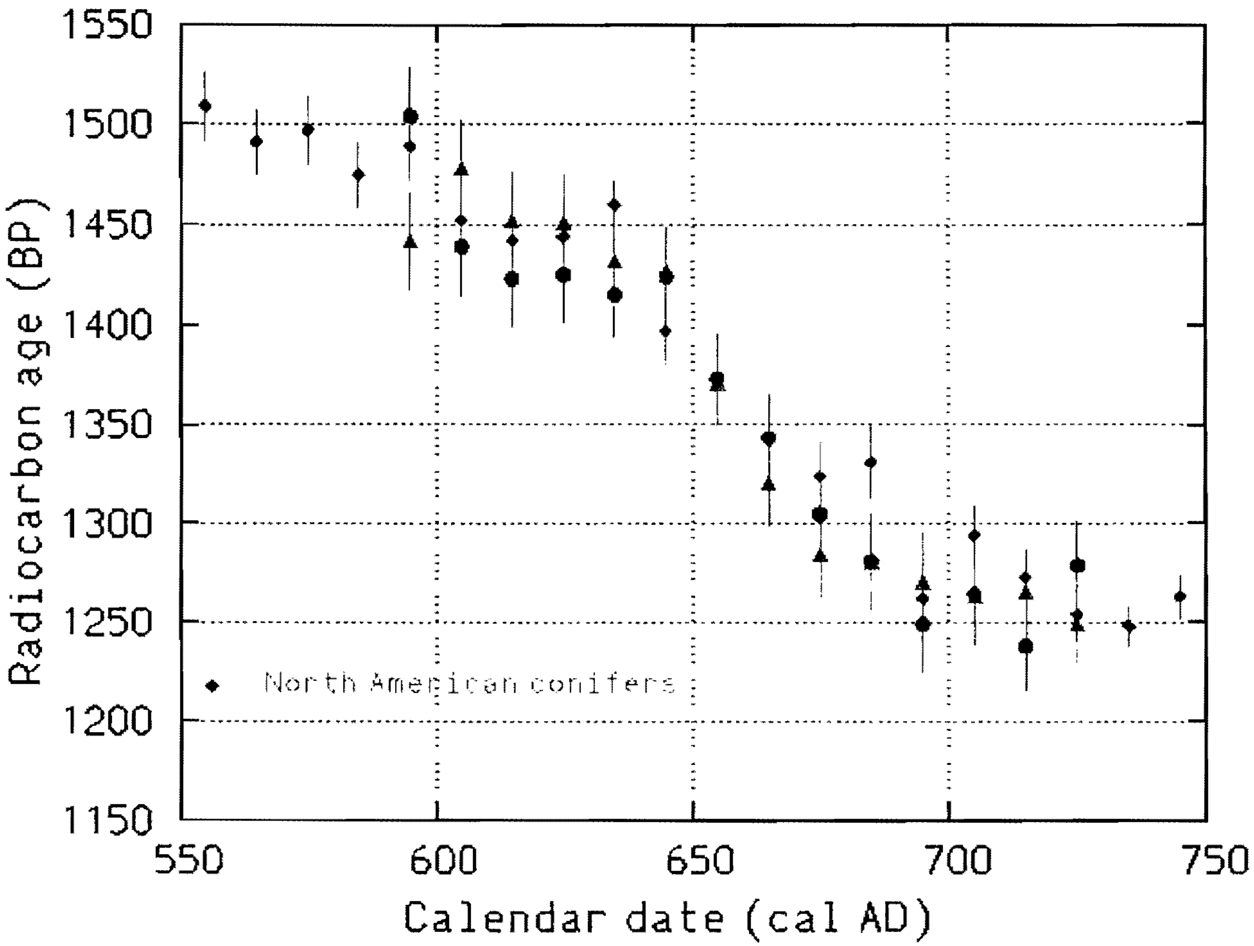
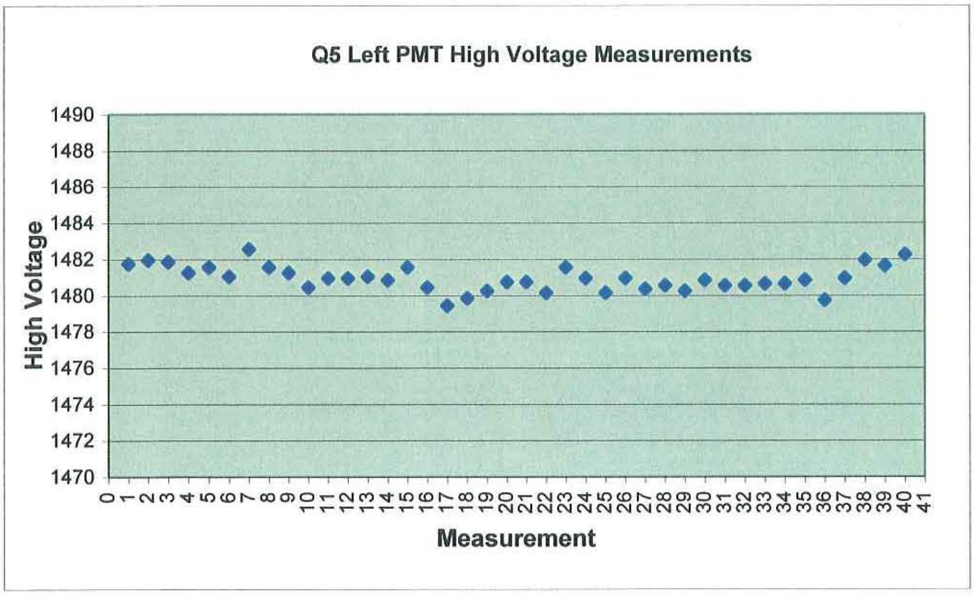
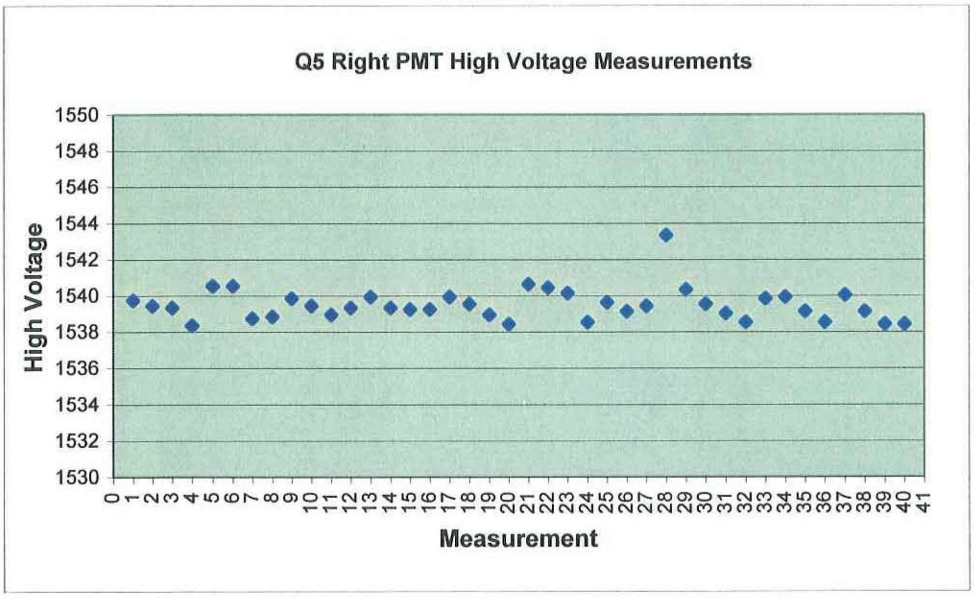


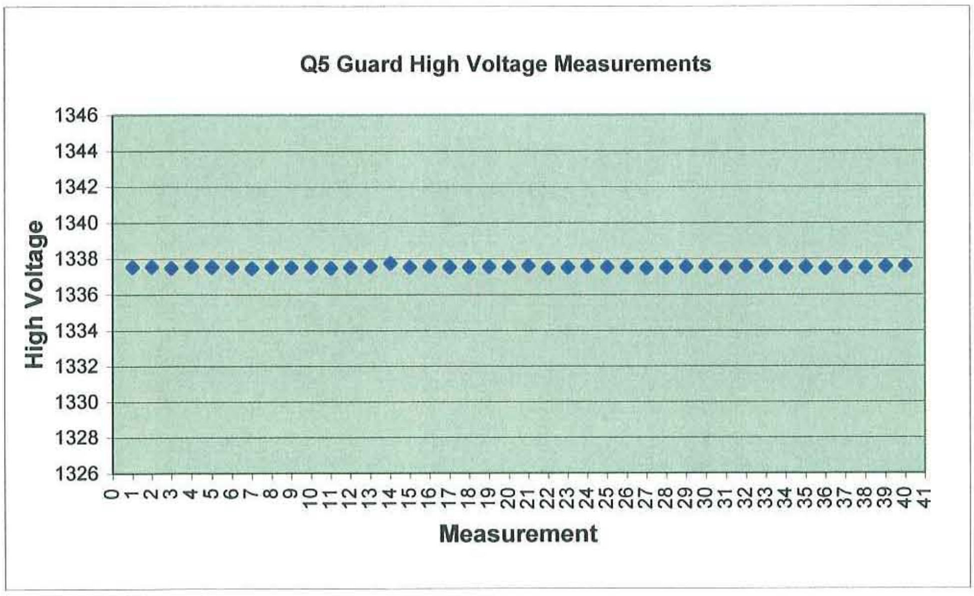
Figure 4. Brabstown decadal replicates plotted with respect to north American conifers (Stuiver *et al* 1998b)



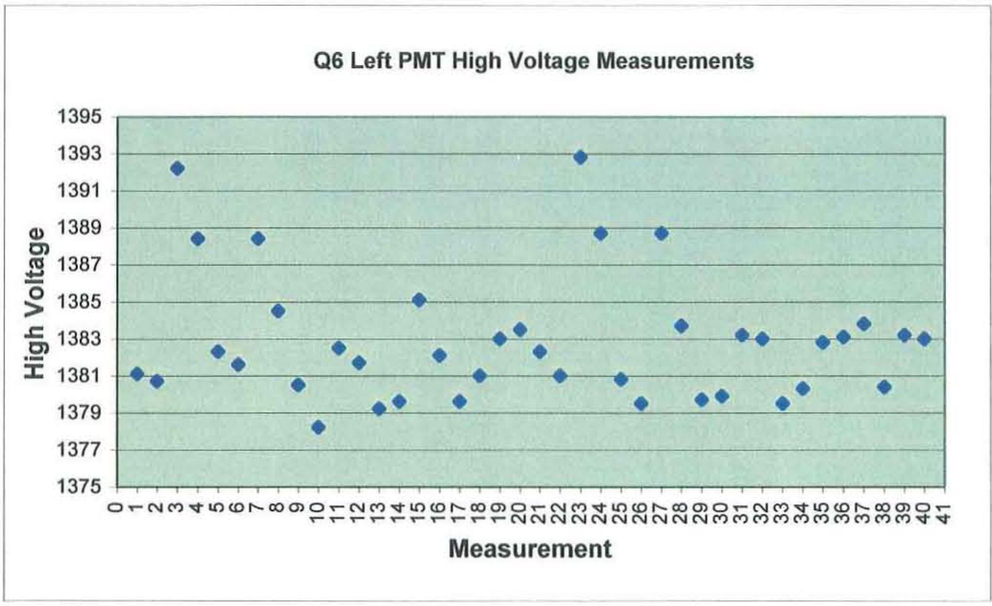
Q5 Left PMT High Voltage Measurements
High Voltage
Measurement



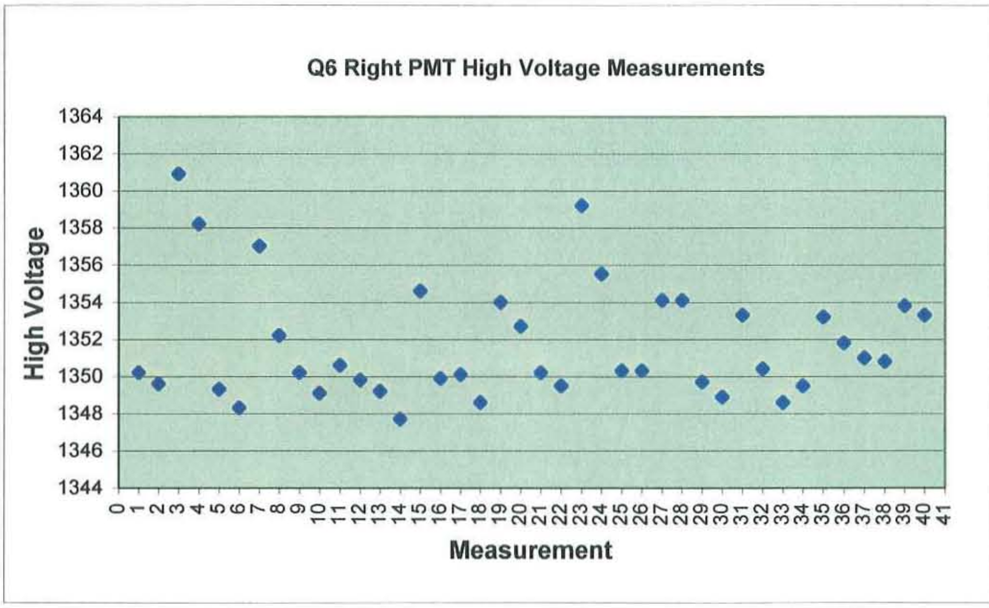
Q5 Right PMT High Voltage Measurements
High Voltage
Measurement



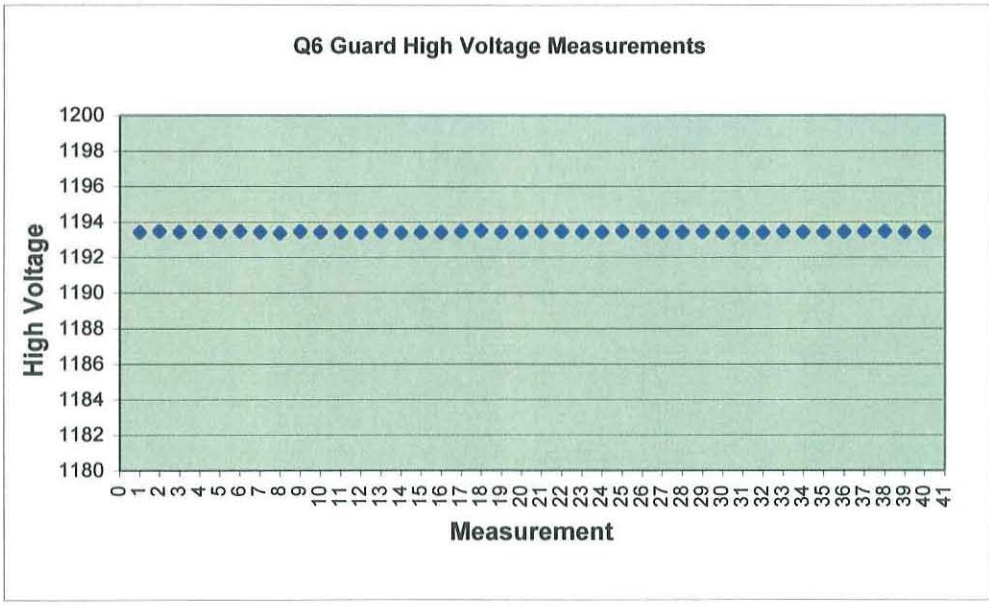
Q5 Guard High Voltage Measurements
High Voltage
Measurement



Q6 Left PMT High Voltage Measurements
High Voltage
Measurement



Q6 Right PMT High Voltage Measurements
High Voltage
Measurement



Q6 Guard High Voltage Measurements
High Voltage
Measurement

Table 1. Q5 vial selection according to deviation from mean counts per minute (CPM) in a background (BGD) count

Vial	Mean BGD CPM (04/06/98 - 05/10/98) Ch 200-600	Deviation from mean	Order of dev. from mean	Mean BGD CPM (04/06/98 - 05/10/98) Ch 108-568	Deviation from mean	Order of dev. from mean
16	0.7160	-0.0080	5	0.7820	-0.0039	1
33	0.7000	0.0080	6	0.7690	0.0091	5
46	0.7360	-0.0280	9	0.8250	-0.0469	10
55	0.6670	0.0410	10	0.7430	0.0351	9
73	0.7100	-0.0020	1	0.7740	0.0041	2
111	0.7240	-0.0160	8	0.7900	-0.0119	7
118	0.7040	0.0040	2	0.7710	0.0071	3
138	0.7150	-0.0070	3	0.7870	-0.0089	4
144	0.6930	0.0150	7	0.7500	0.0281	8
172	0.7150	-0.0070	4	0.7900	-0.0119	6
Mean=	0.7080			0.7781		

Table 2. Q6 vial selection according to deviation from mean counts per minute (background count)

Vial	Mean BGD CPM (04/06/98 - 05/10/98) Ch 200-600	Deviation from mean	Order of dev. from mean	Mean BGD CPM (04/06/98 - 05/10/98) Ch 108-568	Deviation from mean	Order of dev. from mean
1	0.7630	0.0046	3	0.8760	-0.0031	1
2	0.7720	-0.0044	2	0.8800	-0.0071	4
19	0.7740	-0.0064	4	0.8790	-0.0061	3
28	0.7530	0.0146	8	0.8400	0.0329	9
82	0.7600	0.0076	5	0.8550	0.0179	7
120	0.7560	0.0116	6	0.8650	0.0079	5
140	0.7910	-0.0234	10	0.9180	-0.0451	10
145	0.7560	0.0116	7	0.8500	0.0229	8
164	0.7680	-0.0004	1	0.8770	-0.0041	2
195	0.7830	-0.0154	9	0.8890	-0.0161	6
Mean=	0.7676			0.8729		

(shaded) 6 vials with smallest deviation from mean CPM

Note: Weight loss considered to decide between selection of vial 82 (0.00474g) and vial 195 (0.00665g) above. Vial 82 was selected.

Table 4. Calculation of Q5 corrected Oxalic Acid counts per minute per gram (CPM/g)

Vial Number	Start Weight	Mean Counting Weight	Counts per Minute (CPM)	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	CPM/g corr. for 1950 Value
16	2.62852	2.62539	38.107	-17.952	0.985904	0.782	37.30178	14.20809	14.00781374	10.44842827
33	2.62621	2.624255	38.035	-17.952	0.985904	0.769	37.24278	14.19175	13.99170651	10.43641389
73	2.62712	2.624765	38.165	-17.952	0.985904	0.774	37.36778	14.23662	14.03593989	10.46940757
118	2.6266	2.62247	38.041	-17.952	0.985904	0.771	37.24678	14.20294	14.00273383	10.44463916
138	2.62685	2.621155	37.994	-17.952	0.985904	0.787	37.18378	14.18603	13.98606242	10.43220396
172	2.62779	2.62089	38.134	-17.952	0.985904	0.79	37.32078	14.23974	14.03901205	10.47169909

Table 5. Calculation of Q6 corrected Oxalic Acid counts per minute per gram (CPM/g)

Vial Number	Start Weight	Mean Counting Weight	CPM	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	CPM/g corr. for 1950 Value
1	2.62666	2.623215	37.865	-17.927	0.985854	0.876	36.96578	14.09178	13.89244194	10.36237244
2	2.62709	2.625575	37.798	-17.927	0.985854	0.88	36.89478	14.05208	13.85329554	10.33317314
19	2.62556	2.624265	37.81	-17.927	0.985854	0.879	36.90778	14.06404	13.86509462	10.34197408
82	2.62728	2.625815	37.832	-17.927	0.985854	0.855	36.95378	14.07326	13.87418071	10.34875139
120	2.62641	2.6254	37.745	-17.927	0.985854	0.865	36.85678	14.03854	13.83994972	10.32321849
164	2.62607	2.623655	37.754	-17.927	0.985854	0.877	36.85378	14.04673	13.84802744	10.32924367

Appendix 2. Vial selection according to weight range

	VIAL No.	WEIGHT (g)	Wt.Range of 10 vials (g)		VIAL No.	WEIGHT (g)	Wt.Range of 10 vials (g)		VIAL No.	WEIGHT (g)	Wt.Range of 10 vials (g)		VIAL No.	WEIGHT (g)	Wt.Range of 10 vials (g)
1	108	11.98774	0.10032	51	34	12.16935	0.02376	101	18	12.23159	0.01485	151	182	12.31099	0.01511
2	21	12.01488	0.07403	52	117	12.16953	0.0244	102	74	12.23307	0.01954	152	103	12.311	0.01642
3	15	12.01811	0.07184	53	22	12.17202	0.02333	103	89	12.23461	0.01852	153	154	12.312	0.01705
4	38	12.0199	0.07067	54	3	12.18094	0.01515	104	61	12.23489	0.01915	154	194	12.31421	0.0159
5	30	12.0664	0.02478	55	110	12.1866	0.01145	105	141	12.23878	0.01539	155	131	12.31772	0.01309
6	104	12.08239	0.01141	56	51	12.18769	0.01131	106	126	12.24052	0.01413	156	184	12.31939	0.02003
7	23	12.08374	0.01028	57	127	12.18785	0.01185	107	68	12.24436	0.01144	157	85	12.32248	0.0202
8	27	12.08533	0.01469	58	106	12.19149	0.00828	108	142	12.24587	0.01083	158	166	12.32334	0.02226
9	9	12.08598	0.01582	59	87	12.19183	0.00812	109	191	12.24641	0.01192	159	102	12.32513	0.02108
10	121	12.08806	0.01666	60	4	12.19311	0.00694	110	136	12.24644	0.01579	160	193	12.3261	0.02503
11	6	12.08891	0.01679	61	14	12.19393	0.00662	111	63	12.25261	0.01094	161	97	12.32742	0.03437
12	24	12.08995	0.0161	62	13	12.19535	0.00562	112	161	12.25313	0.01219	162	147	12.32905	0.03532
13	93	12.09057	0.01703	63	107	12.19609	0.00557	113	52	12.25404	0.01181	163	153	12.33011	0.03605
14	48	12.09118	0.02049	64	56	12.19805	0.00517	114	100	12.25417	0.01239	164	150	12.33081	0.03548
15	91	12.0938	0.02077	65	145	12.199	**0.00513**	115	37	12.25465	0.01197	165	71	12.33942	0.02889
16	20	12.09402	0.0225	66	140	12.1997	0.00524	116	98	12.2558	0.0122	166	151	12.34268	0.02833
17	133	12.10002	0.02123	67	1	12.19977	0.00569	117	96	12.2567	0.01238	167	59	12.3456	0.05636
18	31	12.1018	0.02338	68	82	12.19995	0.00632	118	109	12.25833	0.01138	168	90	12.34621	-
19	58	12.10472	0.02158	69	120	12.20005	0.0067	119	155	12.26223	0.00804	169	146	12.35113	-
20	26	12.1057	0.02281	70	2	12.20055	0.00705	120	53	12.26355	0.00864	170	115	12.36179	-
21	44	12.10605	0.02268	71	28	12.20097	0.00696	121	183	12.26532	0.00701	171	137	12.36437	-
22	78	12.1076	0.0222	72	195	12.20166	0.0065	122	54	12.26585	0.00688	172	143	12.36616	-
23	42	12.11167	0.01925	73	19	12.20322	0.00532	123	135	12.26656	0.00617	173	139	12.36629	-
24	49	12.11457	0.01808	74	16[illegible]	12.20413	0.00596	124	124	12.26662	0.00754	174	114	12.36831	-
25	35	12.11652	0.01614	75	128	12.20494	0.00538	125	41	12.268	0.00693	175	62	12.37101	-
26	50	12.12125	0.01196	76	55	12.20546	**0.00494**	126	152	12.26908	0.00612	176	181	12.40196	-
27	99	12.12518	0.01126	77	33	12.20627	0.00546	127	12	12.26971	0.00611				
28	72	12.1263	0.01287	78	16	12.20675	0.006	128	176	12.27027	0.00638				
29	84	12.12851	0.01339	79	73	12.2076	0.00637	129	10	12.27219	0.00689				
30	148	12.12873	0.01526	80	172	12.20793	0.00659	130	112	12.27233	0.00732				
31	40	12.1298	0.01652	81	118	12.20816	0.0092	131	81	12.27273	0.0132				
32	43	12.13092	0.02036	82	138	12.20854	0.00937	132	174	12.27273	0.01648				
33	57	12.13265	0.01922	83	46	12.21009	0.0081	133	149	12.27416	0.01976				
34	11	12.13266	0.02302	84	111	12.21032	0.01048	134	122	12.27493	0.01981				
35	8	12.13321	0.02322	85	144	12.2104	0.01246	135	32	12.2752	0.02007				
36	77	12.13644	0.02186	86	47	12.21173	0.01289	136	165	12.27582	0.02139				
37	130	12.13917	0.02439	87	171	12.21275	0.01217	137	7	12.27665	0.02167				
38	70	12.1419	0.0234	88	65	12.21397	0.01459	138	134	12.27908	0.02403				
39	29	12.14399	0.02176	89	119	12.21452	0.01596	139	60	12.27965	0.02549				
40	80	12.14632	0.01966	90	156	12.21736	0.01402	140	113	12.28593	0.02198				
41	94	12.15128	0.01777	91	129	12.21791	0.01347	141	95	12.28921	0.02069				
42	76	12.15187	0.01748	92	45	12.21819	0.0134	142	162	12.29392	0.01707				
43	36	12.15568	0.01385	93	123	12.2208	0.01227	143	79	12.29474	0.01626				
44	5	12.15643	0.01559	94	101	12.22286	0.01175	144	25	12.29527	0.01673				
45	66	12.1583	0.02264	95	17	12.22462	0.01027	145	69	12.29721	0.017				
46	185	12.16356	0.02304	96	192	12.22492	0.01386	146	116	12.29832	0.0194				
47	86	12.1653	0.02239	97	132	12.22856	0.01196	147	75	12.30311	0.01628				
48	92	12.16575	0.0221	98	64	12.23048	0.01388	148	125	12.30514	0.01734				
49	83	12.16598	0.02551	99	105	12.23138	0.01449	149	88	12.30791	0.01543				
50	39	12.16905	0.02278	100	173	12.23138	0.01503	150	67	12.3099	0.01523				

0.00494 lowest weight range

(shaded) 10 selected vials

Table 3(a). Q5 Weight loss data

Q5 Background Count. Vial weight losses with time.

Vial	Date Filled/start	Weight Loss by 06/07/98	Weight Loss by 03/08/98	Weight Loss by 07/09/98	Weight Loss by 05/10/98
16	04/06/98	0.00223	0.00497	0.00927	0.01493
33	04/06/98	0.00367	0.00664	0.00942	0.01463
46	04/06/98	0.00000	0.00029	0.00154	0.00418
55	04/06/98	0.00128	0.00365	0.00735	0.01159
73	04/06/98	0.00313	0.00682	0.01175	0.01768
111	04/06/98	0.00103	0.00239	0.00559	0.01175
118	04/06/98	0.00101	0.00175	0.00349	0.00633
138	04/06/98	0.00067	0.00125	0.00232	0.00505
144	04/06/98	0.00081	0.00195	0.00476	0.00890
172	04/06/98	0.00019	0.00029	0.00109	0.00365

Table 3(b). Q6 Weight loss data

Q6 Background Count. Vial weight losses with time.

Vial	Date Filled/start	Weight Loss by 03/07/98	Weight Loss by 03/08/98	Weight Loss by 07/09/98	Weight Loss by 05/10/98
1	04/06/98	0.00113	0.00273	0.00500	0.00817
2	04/06/98	0.00087	0.00124	0.00214	0.00464
19	04/06/98	0.00055	0.00067	0.00132	0.00319
28	04/06/98	0.00064	0.00109	0.00233	0.00518
82	04/06/98	0.00011	0.00092	0.00226	0.00474
120	04/06/98	0.00041	0.00046	0.00105	0.00324
140	04/06/98	0.00049	0.00056	0.00123	0.00295
145	04/06/98	0.00014	0.00000	0.00043	0.00258
164	04/06/98	0.00049	0.00065	0.00147	0.00329
195	04/06/98	0.00142	0.00237	0.00387	0.00665

Table 4. Calculation of Q5 corrected Oxalic Acid counts per minute per gram (CPM/g)

Vial Number	Start Weight	Mean Counting Weight	Counts per Minute (CPM)	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	CPM/g corr. for 1950 Value
16	2.62852	2.62539	38.107	-17.952	0.985904	0.782	37.30178	14.20809	14.00781374	10.44842827
33	2.62621	2.624255	38.035	-17.952	0.985904	0.769	37.24278	14.19175	13.99170651	10.43641389
73	2.62712	2.624765	38.165	-17.952	0.985904	0.774	37.36778	14.23662	14.03593989	10.46940757
118	2.6266	2.62247	38.041	-17.952	0.985904	0.771	37.24678	14.20294	14.00273383	10.44463916
138	2.62685	2.621155	37.994	-17.952	0.985904	0.787	37.18378	14.18603	13.98606242	10.43220396
172	2.62779	2.62089	38.134	-17.952	0.985904	0.79	37.32078	14.23974	14.03901205	10.47169909

Table 5. Calculation of Q6 corrected Oxalic Acid counts per minute per gram (CPM/g)

Vial Number	Start Weight	Mean Counting Weight	CPM	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	CPM/g corr. for 1950 Value
1	2.62666	2.623215	37.865	-17.927	0.985854	0.876	36.96578	14.09178	13.89244194	10.36237244
2	2.62709	2.625575	37.798	-17.927	0.985854	0.88	36.89478	14.05208	13.85329554	10.33317314
19	2.62556	2.624265	37.81	-17.927	0.985854	0.879	36.90778	14.06404	13.86509462	10.34197408
82	2.62728	2.625815	37.832	-17.927	0.985854	0.855	36.95378	14.07326	13.87418071	10.34875139
120	2.62641	2.6254	37.745	-17.927	0.985854	0.865	36.85678	14.03854	13.83994972	10.32321849
164	2.62607	2.623655	37.754	-17.927	0.985854	0.877	36.85378	14.04673	13.84802744	10.32924367

Table 6a. Calculation of error multiplier for Q5

VIAL	OX CPM/G	% OX ERROR	BGD ERROR	ERROR OXALIC	BGD + OXALIC ERROR	$ERROR^2$
16	10.44840	0.129336	0.002746826	0.013513543	0.013789884	0.000190161
33	10.43640	0.129459	0.002727816	0.013510859	0.013783479	0.000189984
73	10.46940	0.128827	0.002743006	0.013487414	0.013763518	0.000189434
118	10.44460	0.129043	0.002732287	0.013478025	0.013752184	0.000189123
138	10.43220	0.129123	0.002759824	0.013470370	0.013750181	0.000189067
172	10.47170	0.128886	0.002765579	0.013496555	0.013776989	0.000189805
STD DEV	0.01661057					
MEAN	10.45045					

Error Multiplier 1.206341031

Table 6b. Calculation of error multiplier for Q6

VIAL	OX CPM/G	% OX ERROR	BGD ERROR	ERROR OXALIC	BGD + OXALIC ERROR	$ERROR^2$
1	10.36237	0.127712	0.003381607	0.013233993	0.013659203	0.000186574
2	10.33320	0.127826	0.003596360	0.013208516	0.013689365	0.000187399
19	10.34200	0.127805	0.003620134	0.013217593	0.013704384	0.000187810
82	10.34880	0.128555	0.003584311	0.013303900	0.013778281	0.000189841
120	10.32320	0.128703	0.003602028	0.013286268	0.013765883	0.000189500
164	10.32920	0.127900	0.003626220	0.013211047	0.013699680	0.000187681
STD DEV	0.01433049					
MEAN	10.33980					

Error Multiplier 1.044786082

Table 7. Student 't' values for samples, Q3693 and Q3865 cross matching into the Brabstown site chronology.

QUB number	Q3691	Q3693	Q3697	Q3865	Q4748	Q4749
Q3691	-	5.77***	10.91***	4.43**	6.42***	5.04***
Q3693	-	-	5.19**	4.61**	7.12**	3.12vwm
Q3697	-	-	-	3.32nsm	6.09***	-
Q3865	-	-	-	-	3.80*	5.55***
Q4748	-	-	-	-	-	5.72***

Table 8. Student 't' values for the Brabstown site chronology compared with a series of dated local site chronologies.

Site chronology name	Brabstown, Co. Kilkenny
Ballyroe, Co. Wexford	8.54***
Ballyrafton, Co. Kilkenny	7.44***
Newtown, Co. Tipperary	7.18***
Ballygeardra, Co. Kilkenny	6.29***
Ballygormill South, Co. Laois	5.98***
Ballydowane West, Co. Waterford	5.75***
Ballynoe, Co. Cork	5.68***
Farranmareen, Co. Cork	5.47***
Cappagh South, Co. Clare	5.36***
Cloongowna, Co. Clare	5.19***
Templenacroha, Co. Wexford	5.03***

Table 9. Dating of the Brabstown known-age wood series using weighted mean values of all Oxalic II Acid data

Laboratory ID	Sample Decade Centred on	Counter	Sample Corrected CPM/g	Oxalic Weighted 1950 Value	Sample CPM/g corr. for Ox. 1950	^{14}C years BP	^{14}C years Error	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Error
UB-4383	AD 595 S1	Q6	8.54916	10.308899	0.8292990	1504	24	-24.582	0.028
UB-4384	AD 595 S2	Q6	8.61442	10.308899	0.8356295	1442	24	-24.612	0.014
UB-4385	AD 605 S1	Q6	8.61843	10.308899	0.8360185	1439	24	-23.980	0.002
UB-4386	AD 605 S2	Q6	8.57622	10.308899	0.8319240	1478	24	-24.124	0.004
UB-4387	AD 615 S1	Q5	8.73918	10.433449	0.8376118	1423	24	-23.812	0.012
UB-4388	AD 615 S2	Q5	8.70800	10.433449	0.8346233	1452	24	-23.848	0.012
UB-4389	AD 625 S1	Q5	8.73765	10.433449	0.8374652	1425	24	-24.306	0.012
UB-4390	AD 625 S2	Q5	8.70872	10.433449	0.8346923	1451	24	-24.215	0.018
UB-4391	AD 635 S1	Q6	8.64430	10.308899	0.8385280	1415	22	-24.343	0.014
UB-4392	AD 635 S2	Q6	8.62592	10.308899	0.8367450	1432	22	-24.338	0.014
UB-4393	AD 645 S1	Q6	8.63460	10.308899	0.8375870	1424	22	-24.715	0.008
UB-4394	AD 645 S2	Q6	8.63310	10.308899	0.8374415	1425	22	-24.709	0.004
UB-4395	AD 655 S1	Q5	8.79472	10.433449	0.8429351	1373	22	-24.984	0.004
UB-4396	AD 655 S2	Q5	8.79633	10.433449	0.8430894	1371	22	-25.091	0.012
UB-4397	AD 665 S1	Q6	8.72160	10.308899	0.8460263	1343	22	-23.012	0.006
UB-4398	AD 665 S2	Q6	8.74571	10.308899	0.8483651	1321	22	-25.418	0.006
UB-4399	AD 675 S1	Q5	8.86852	10.433449	0.8500085	1305	22	-25.982	0.012
UB-4400	AD 675 S2	Q5	8.89077	10.433449	0.8521410	1285	22	-25.957	0.008
UB-4401	AD 685 S1	Q5	8.89527	10.433449	0.8525723	1281	24	-25.556	0.006
UB-4402	AD 685 S2	Q5	8.89573	10.433449	0.8526164	1281	24	-25.503	0.008
UB-4403	AD 695 S1	Q5	8.93079	10.433449	0.8559768	1249	24	-25.726	0.014
UB-4404	AD 695 S2	Q5	8.90619	10.433449	0.8536190	1271	24	-25.814	0.006
UB-4405	AD 705 S1	Q5	8.91408	10.433449	0.8543752	1264	24	-25.733	0.004
UB-4406	AD 705 S2	Q5	8.91585	10.433449	0.8545448	1263	24	-25.903	0.008
UB-4407	AD 715 S1	Q6	8.83646	10.308899	0.8571682	1238	22	-25.229	0.006
UB-4408	AD 715 S2	Q6	8.80608	10.308899	0.8542212	1266	22	-25.208	0.016
UB-4409	AD 725 S1	Q6	8.79139	10.308899	0.8527962	1279	22	-25.457	0.018
UB-4410	AD 725 S2	Q6	8.82455	10.308899	0.8560128	1249	22	-25.457	0.018

Table 10. Offsets of Brabstown decadal oak measurements

a) sample1 with respect to sample 2

Sample decade centred on	Difference (sample 1-sample2)	Standard deviation
AD 595	62	33.9
AD 605	-39	33.9
AD 615	-29	33.9
AD 625	-26	33.9
AD 635	-17	31.1
AD 645	-3	31.1
AD 655	2	31.1
AD 665	22	31.1
AD 675	20	31.1
AD 685	0	33.9
AD 695	-22	33.9
AD 705	1	33.9
AD 715	-28	31.1
AD 725	30	31.1

Number of comparisons= 14

Average difference= -1.929

Average standard deviation in difference= 32.527

Mean difference= -1.439 +/- 8.669

Std. dev.=sqrt(sample variance)= 27.467

k = Std.dev./Avg. s.d.= 0.844

b) Brabstown bi-decadal average (final) with respect to Belfast data (Pearson *et al* 1986)

Sample bi-decade centred on	Difference (Brabs.ave-Belfast 1986)	Standard deviation
AD 610	-15	21.6
AD 630	28.1	21.4
AD 650	-9.2	16.3
AD 670	-15.5	21.1
AD 690	-8.5	21.6
AD 710	-24.7	21.4
AD 730	18	19.7

Number of comparisons= 7

Average difference=-3.829

Average standard deviation in difference= 20.435

Mean difference= -3.815 +/- 7.612

Std. dev.=sqrt(sample variance)= 18.652

k = Std.dev./Avg. s.d.= 0.913

c) Brabstown decadal replicates with respect to INTCAL98 (Stuiver *et al* 1998a)

Sample decade centred on	Difference (Brabs.reps-INTCAL98)	Standard deviation
AD 595	-30.4	24.8
AD 605	0.7	23.9
AD 615	-24.8	30.7
AD 625	2.8	24.4
AD 635	-28.6	20.8
AD 645	14.4	22.1
AD 655	-23.6	21.5
AD 665	-9.7	24
AD 675	-34.3	24
AD 685	-36.7	25.3
AD 695	-10.5	24.7
AD 705	-30.7	22.2
AD 715	-29.1	20.7
AD 725	7.9	20.6

Number of comparisons= 14

Average difference= -16.614

Average standard deviation in difference= 23.540

Mean difference= -16.120 +/- 6.195

Std. dev.=sqrt(sample variance)= 17.302

k = Std.dev./Avg. s.d.= 0.735

d) Brabstown replicates weighted average with respect to North American conifers (Stuiver *et al* 1998b)

Sample decade centred on	Difference (Brabs.reps-UW conifers)	Standard deviation
595 AD	-16	24
605 AD	6.5	22.7
615 AD	-4.5	36.2
625 AD	-6	23.3
635 AD	-36.5	19.7
645 AD	28.5	23.1
655 AD	1	22.3
665 AD	-10	23.1
675 AD	-29	23.1
685 AD	-50	24.8
695 AD	-2	23.3
705 AD	-30.5	22.7
715 AD	-21	20.3
725 AD	10	20.3

Number of comparisons= 14

Average difference= -11.393

Average standard deviation in difference= 23.495

Mean difference= -11.687 +/- 6.114

Std. dev.=sqrt(sample variance)= 21.030

k = Std.dev./Avg. s.d.= 0.895

Appendix 1. Catalogue of vial weight (g) arranged in ascending order

	VIAL No.	WEIGHT (g)
1	108	11.98774
2	21	12.01488
3	15	12.01811
4	38	12.0199
5	30	12.0664
6	104	12.08239
7	23	12.08374
8	27	12.08533
9	9	12.08598
10	121	12.08806
11	6	12.08891
12	24	12.08995
13	93	12.09057
14	48	12.09118
15	91	12.0938
16	20	12.09402
17	133	12.10002
18	31	12.1018
19	58	12.10472
20	26	12.1057
21	44	12.10605
22	78	12.1076
23	42	12.11167
24	49	12.11457
25	35	12.11652
26	50	12.12125
27	99	12.12518
28	72	12.1263
29	84	12.12851
30	148	12.12873
31	40	12.1298
32	43	12.13092
33	57	12.13265
34	11	12.13266
35	8	12.13321
36	77	12.13644
37	130	12.13917
38	70	12.1419
39	29	12.14399
40	80	12.14632
41	94	12.15128
42	76	12.15187
43	36	12.15568
44	5	12.15643
45	66	12.1583
46	185	12.16356
47	86	12.1653
48	92	12.16575
49	83	12.16598
50	39	12.16905
51	34	12.16935
52	117	12.16953
53	22	12.17202
54	3	12.18094
55	110	12.1866
56	51	12.18769
57	127	12.18785
58	106	12.19149
59	87	12.19183
60	4	12.19311
61	197	12.19366
62	14	12.19393
63	13	12.19535
64	107	12.19609
65	56	12.19805
66	145	12.199
67	140	12.1997
68	1	12.19977
69	82	12.19995
70	120	12.20005
71	2	12.20055
72	28	12.20097
73	195	12.20166
74	19	12.20322
75	164	12.20413
76	128	12.20494
77	55	12.20546
78	33	12.20627
79	16	12.20675
80	196	12.20712
81	73	12.2076
82	172	12.20793
83	118	12.20816
84	138	12.20854
85	46	12.21009
86	111	12.21032
87	144	12.2104
88	47	12.21173
89	171	12.21275
90	65	12.21397
91	119	12.21452
92	156	12.21736
93	129	12.21791
94	45	12.21819
95	167	12.21867
96	123	12.2208
97	101	12.22286
98	17	12.22462
99	192	12.22492
100	132	12.22856
101	64	12.23048
102	105	12.23138
103	173	12.23138
104	18	12.23159
105	74	12.23307
106	89	12.23461
107	61	12.23489
108	141	12.23878
109	126	12.24052
110	68	12.24436
111	142	12.24587
112	159	12.24627
113	191	12.24641
114	136	12.24644
115	178	12.24899
116	63	12.25261
117	161	12.25313
118	52	12.25404
119	100	12.25417
120	37	12.25465
121	98	12.2558
122	96	12.2567
123	109	12.25833
124	188	12.25943
125	155	12.26223
126	53	12.26355
127	183	12.26532
128	54	12.26585
129	135	12.26656
130	124	12.26662
131	41	12.268
132	152	12.26908
133	12	12.26971
134	176	12.27027
135	10	12.27219
136	189	12.27226
137	112	12.27233
138	81	12.27273
149	174	12.27273
140	149	12.27416
141	122	12.27493
142	32	12.2752
143	165	12.27582
144	7	12.27665
145	134	12.27908
146	60	12.27965
147	190	12.28106
148	177	12.28113
149	113	12.28593
150	95	12.28921
151	162	12.29392
152	79	12.29474
153	25	12.29527
154	69	12.29721
155	116	12.29832
156	179	12.30232
157	75	12.30311
158	125	12.30514
159	88	12.30791
160	67	12.3099
161	182	12.31099
162	103	12.311
163	154	12.312
164	194	12.31421
165	131	12.31772
166	184	12.31939
167	85	12.32248
168	166	12.32334
169	102	12.32513
170	193	12.3261
171	199	12.32649
172	97	12.32742
173	160	12.32854
174	147	12.32905
175	170	12.32953
176	153	12.33011
177	150	12.33081
178	187	12.33359
179	198	12.33519
180	71	12.33942
181	151	12.34268
182	168	12.34396
183	158	12.34432
184	180	12.34515
185	59	12.3456
186	90	12.34621
187	186	12.34728
188	146	12.35113
189	157	12.35747
190	115	12.36179
191	137	12.36437
192	143	12.36616
193	139	12.36629
194	114	12.36831
195	62	12.37101
196	181	12.40196
197	163	12.43148
198	169	12.43463
199	175	12.45786

Appendix 3. Q5 and Q6 High Voltage Measurements July-August 1998

Q5 HIGH VOLTAGE MEASUREMENTS

VIAL No.	Position	Date	H.V.L.	H.V.R	H.V.G.
16	1	27/07/98	1481.7	1539.7	1337.49
16	1	30/07/98	1481.9	1539.4	1337.51
16	1	14/08/98	1481.8	1539.3	1337.43
16	1	18/08/98	1481.2	1538.3	1337.53
46	2	28/07/98	1481.5	1540.5	1337.5
46	2	30/07/98	1481	1540.5	1337.5
46	2	14/08/98	1482.5	1538.7	1337.42
46	2	17/08/98	1481.5	1538.8	1337.5
73	3	28/07/98	1481.2	1539.8	1337.48
73	3	29/07/98	1480.4	1539.4	1337.5
73	3	14/08/98	1480.9	1538.9	1337.43
73	3	17/08/98	1480.9	1539.3	1337.48
118	4	29/07/98	1481	1539.9	1337.52
118	4	31/07/98	1480.8	1539.3	1337.7
118	4	17/08/98	1481.5	1539.2	1337.5
118	4	18/08/98	1480.4	1539.2	1337.53
144	5	29/07/98	1479.4	1539.9	1337.5
144	5	30/07/98	1479.8	1539.5	1337.49
144	5	18/08/98	1480.2	1538.9	1337.51
144	5	20/08/98	1480.7	1538.4	1337.5
33	41	30/07/98	1480.7	1540.6	1337.56
33	41	03/08/98	1480.1	1540.4	1337.44
33	41	13/08/98	1481.5	1540.1	1337.47
33	41	18/08/98	1480.9	1538.5	1337.53
55	42	28/07/98	1480.1	1539.6	1337.5
55	42	30/07/98	1480.9	1539.1	1337.5
55	42	14/08/98	1480.3	1539.4	1337.44
55	42	17/08/98	1480.5	1543.3	1337.48
111	43	29/07/98	1480.2	1540.3	1337.51
111	43	31/07/98	1480.8	1539.5	1337.51
111	43	17/08/98	1480.5	1539	1337.48
111	43	19/08/98	1480.5	1538.5	1337.53
138	44	29/07/98	1480.6	1539.8	1337.51
138	44	03/08/98	1480.6	1539.9	1337.47
138	44	17/08/98	1480.8	1539.1	1337.5
138	44	25/08/98	1479.7	1538.49	1337.42
172	45	30/07/98	1480.9	1540	1337.5
172	45	03/08/98	1481.9	1539.1	1337.47
172	45	18/08/98	1481.6	1538.4	1337.52
172	45	21/08/98	1482.2	1538.4	1337.55

Q6 HIGH VOLTAGE MEASUREMENTS

VIAL No.	Position	Date	H.V.L.	H.V.R	H.V.G.
1	1	28/07/98	1381.1	1350.2	1193.4
1	1	29/07/98	1380.7	1349.6	1193.46
1	1	13/08/98	1392.2	1360.9	1193.43
1	1	14/08/98	1388.4	1358.2	1193.42
19	2	28/07/98	1382.3	1349.3	1193.46
19	2	29/07/98	1381.6	1348.3	1193.45
19	2	14/08/98	1388.4	1357	1193.43
19	2	19/08/98	1384.5	1352.2	1193.37
82	3	30/07/98	1380.5	1350.2	1193.46
82	3	31/07/98	1378.2	1349.1	1193.43
82	3	21/08/98	1382.5	1350.6	1193.43
82	3	24/08/98	1381.7	1349.8	1193.4
140	4	31/07/98	1379.2	1349.2	1193.47
140	4	03/08/98	1379.6	1347.7	1193.38
140	4	17/08/98	1385.1	1354.6	1193.4
140	4	21/08/98	1382.1	1349.9	1193.4
164	5	03/08/98	1379.6	1350.1	1193.45
164	5	04/08/98	1381	1348.6	1193.5
164	5	17/08/98	1383	1354	1193.42
164	5	18/08/98	1383.5	1352.7	1193.43
2	41	28/07/98	1382.3	1350.2	1193.46
2	41	29/07/98	1381	1349.5	1193.45
2	41	13/08/98	1392.8	1359.2	1193.44
2	41	14/08/98	1388.7	1355.5	1193.42
28	42	29/07/98	1380.8	1350.3	1193.47
28	42	30/07/98	1379.5	1350.3	1193.46
28	42	14/08/98	1388.7	1354.1	1193.43
28	42	20/08/98	1383.7	1354.1	1193.43
120	43	30/07/98	1379.7	1349.7	1193.44
120	43	31/07/98	1379.9	1348.9	1193.4
120	43	17/08/98	1383.2	1353.3	1193.42
120	43	21/08/98	1383	1350.4	1193.4
145	44	31/07/98	1379.5	1348.6	1193.45
145	44	03/08/98	1380.3	1349.5	1193.42
145	44	17/08/98	1382.8	1353.2	1193.42
145	44	18/08/98	1383.1	1351.8	1193.44
195	45	27/07/98	1383.8	1351	1193.45
195	45	03/08/98	1380.4	1350.8	1193.45
195	45	17/08/98	1383.2	1353.8	1193.42
195	45	18/08/98	1383	1353.3	1193.43

High Voltage to the Left Photomultiplier tube (PMT) = H.V.L.
High Voltage to the Right PMT = H.V.R.
Guard High Voltage = H.V.G.

Appendix 4. Comparison of date calculations using Open Window and Balance Point Counting (see McCormac (1992) and Pearson (1983))

Example batch (Q5b) calculated using individual standard data

Background (BGD) counts per minute (CPM) Values

		Q5_BGD0399_V33 CPM	Q5_BGD0399_V33 CPM
Restricted Window	Channel 218-484	0.357	0.357
Open Window	Channel 108-568	0.76	0.76

Oxalic 1950 Value Calculation Q5_OX0399_V16

		Start Weight	Mean Counting Weight	CPM	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Synthesis factor (Syn. fac.)	CPM/g	CPM/g corr. for Mass. Spec.	CPM/g corr. for 1950 Value
Restricted Window	Channel 218-484	2.62783	2.618435	32.507	-17.723	0.985446	0.357	32.12678	12.26946	12.09088896	9.018594078
Open Window	Channel 108-568	2.62783	2.618435	37.791	-17.723	0.985446	0.76	37.00778	14.13355	13.92784956	10.38878299

Radiocarbon Age Calculation

Restricted Window	Channel 218-484	Mean Counting Weight	% sample	CPM	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	Oxalic 1950 Value	Radiocarbon Age BP
	UB-4405	2.62439	100	20.661	-25.733	1.001466	0.357	20.28078	7.727807	7.739136189	9.018594078	1229
	UB-4406	2.62622	100	20.678	-25.903	1.001806	0.357	20.29778	7.728896	7.742853908	9.018594078	1225

Open Window	Channel 108-568	Mean Counting Weight	% sample	CPM	Mass Spec. Value ($\delta^{13}C$ ‰)	Mass Spec. Correction Factor	BGD CPM	CPM corr. for Bgd and Syn.fac.	CPM/g	CPM/g corr. for Mass. Spec.	Oxalic 1950 Value	Radiocarbon Age BP
	UB-4405	2.62439	100	23.974	-25.733	1.001466	0.76	23.35978	8.901032	8.914081153	10.38878299	1230
	UB-4406	2.62622	100	24.143	-25.903	1.001806	0.76	23.37278	8.89978	8.915852914	10.38878299	1228