

Environmental Radiation Monitoring in Hong Kong

Technical Report No. 14

**Carbon-14 Content in Foodstuffs
Consumed in Hong Kong
(1986 to 1995)**

K.C. Tsui, W.M. Leung

**Royal Observatory
HONG KONG**

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by

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1. Introduction

In connection with the construction of the Guangdong Nuclear Power Station (GNPS) at Daya Bay, carbon-14 (C-14) content in foodstuffs consumed in Hong Kong was monitored in the Background Radiation Monitoring Programme (BRMP) by the Royal Observatory since 1986. As the capability of performing sample treatment (benzene synthesis) was not available locally, the measurements were contracted out to the AEA Technology, Harwell, U.K. More than 160 samples of foodstuffs collected in the pre-operational phase of the GNPS between the winter of 1986 and the end of 1989 in Hong Kong were measured and the results were summarised in the report *Background Radiation Monitoring Programme 1987 - 1991* by the Royal Observatory (1992).

The GNPS began operational testing in 1993 and monitoring of C-14 content has been resumed since then. Measurement of C-14 content continued to be performed by the AEA Technology and a total of 25 samples of foodstuffs were measured between 1993 and 1995. Individual measurement results were published in the *Annual Report* by the Royal Observatory each year.

The objectives of this study are :

- (i) to calculate the average decline rate, expressed as halving time (see Appendix A), of C-14 content in foodstuffs consumed in Hong Kong between the BRMP period and more recent years on the assumption that there has been no increase in C-14 content of foodstuffs arising from the operation of the GNPS.
- (ii) to interpolate the values of carbon-14 content between 1990 and 1992.
- (iii) to extrapolate forward for a few years after 1995.

2. Carbon-14 in the Environment

2.1 Sources of Carbon-14

Natural C-14 is produced in the upper atmosphere primarily from nitrogen-14 by capture of neutrons originated by cosmic-ray interactions. The production rate is not constant with time. Short term variations were observed from tree ring measurements carried out for radiocarbon dating. The variations are in general inversely related to solar activity as primary cosmic rays are more likely to be scattered out from the earth's orbit during periods of enhanced solar activity.

Artificial sources of C-14 are mainly from the atmospheric nuclear weapons tests of the 1950s and 1960s and, to a lesser extent, the operation of nuclear reactors. C-14 are produced in nuclear reactors due to neutron capture of nitrogen, carbon or oxygen present as components of the fuel, moderator, structural hardware, or in impurities.

The specific activity of C-14 relative to total carbon content has two major changes in the twentieth century. The first one occurred at the start of the century when the world entered the industrial era. Massive increase in the combustion of fossil fuel released large amount of stable carbon to the exchangeable carbon reservoir thus diluting the specific C-14 content. Another major change occurred in the middle of the century when extensive atmospheric nuclear weapons tests were conducted. C-14 was introduced in the atmosphere up to several times of the natural level. With the tests began to be banned later in the 1960s, the enhanced C-14 level started to decline globally as the isotope was exchanged with stable carbon in larger ocean reservoir. Figures 1 and 2 show these two major changes in the global C-14 level.

Future changes in the global decline, apart from natural fluctuations, will depend on two competing factors, the continued dilution of C-14 by usage of fossil fuel and the output of C-14 by the developing nuclear power industry.

2.2 Properties of Carbon-14

Carbon-14 is a radioisotope of carbon with natural abundance of less than 0.1 percent and physical half life of around 5730 years. C-14 decays to nitrogen-14 by emission of a beta particle with a maximum energy of 156 keV and an average energy of 45 keV.

Roughly 95 percent of exchangeable carbon resides in the oceans. In the atmosphere, around 99 percent of carbon is in the form of carbon dioxide. C-14 produced or released in the atmosphere will enter the carbon cycle of exchangeable carbon reservoirs of atmosphere, biosphere, ocean, ocean sediment and organic shale.

C-14 enters the human body mainly through inhalation of carbon dioxide and ingestion of foodstuffs. Apart from isotopic fractionation at media surfaces, C-14

behaves the same as its stable isotope C-12. As the atmospheric mixing time for carbon dioxide is relatively short, it is usually assumed in the dosimetry of C-14 that environmental C-14 is in equilibrium with that in the terrestrial biosphere such that the specific activity of environmental C-14 is the same as that of biological C-14. This assumption of static equilibrium is used widely except for very localized enhancement or dilution of C-14 due to nearby nuclear facilities or fossil fuel power plants respectively.

3. Sampling Programme and Measurement Method

3.1 Sampling Programme

As part of the BRMP and an on-going Environmental Radiation Monitoring Programme (ERMP) which contains all the essential features of BRMP, samples of various types of foodstuffs typical to the diet of local population and consumed in large quantities were collected at main distribution points and wholesales markets. Particular attention has been given to food produced locally, in Shenzhen and at and around Hong Kong waters.

3.1.1 Terrestrial Foodstuffs

The types of foodstuffs collected included beef, pork, pig's liver, chicken, duck, chicken's offal, duck's offal, rice, pasteurized milk, flowering cabbage (choi sum), white cabbage (pak choi), banana, lychee, mandarin and sugar cane. Samples which were available locally and those imported from China were collected. Sampling frequency was once every quarter for those available throughout the year. As some of the fruits were only available seasonally, they were collected once or twice a year.

3.1.2 Aquatic Foodstuffs

Aquatic foodstuffs sampled included freshwater fish, marine fish, crab, shrimp, squid and shellfish. Only one species of freshwater fish was selected, namely, *aristichthys nobilis* from Shenzhen and Yuen Long. Three species of marine fish, namely, *nemipterus japonicus*, *trichiurus haumela* and *platycephalus indicus*, were collected at and around Hong Kong waters, i.e. Daya Bay, east of Daya Bay, Hong Kong waters and west of Hong Kong. Species of crab, shrimp and squid chosen were *portunus sanguinolentus*, *metapenaeopsis barbata* and *loligo edulis* respectively. They were collected at the same four areas as marine fish. Three types of shellfish samples, namely *tapes philipinarum*, *perna viridis* and *babylonia formosae*, were collected at Hong Kong coastal waters near Cheung Chau, Port Shelter, Tolo Harbour, Castle Peak Bay, Junk Bay and Mirs Bay. Sampling frequency was once every quarter but there was a decreasing trend in the number of samples collected due to poor catches in those areas.

3.2 Measurement Method

Benzene synthesis followed by liquid scintillation counting was chosen for the measurement of C-14 in the foodstuffs samples due to the high counting precision achievable. As techniques of benzene synthesis was not available locally, the measurements were contracted out to AEA Technology, Harwell, U.K.

The edible portion of the samples were extracted and freeze-dried in Hong Kong before delivery to the AEA Technology for further treatment and measurement. After reaching the AEA Technology, freeze-dried samples of the same type but collected in different quarters were bulked to form a composite sample of the year. The sample was combusted in oxygen in a pressure combustion bomb to produce carbon dioxide which was then converted to lithium carbide, acetylene, and finally to benzene. The benzene sample was then added with scintillant and counted in a low level liquid scintillation counter.

4. Results and Discussions

The results of the measurements of C-14 in different sample types are tabulated in Tables 1(a)-(c) and 2(a)-(d) for terrestrial foodstuffs and aquatic foodstuffs respectively.

The mean and standard deviation of each sample type are calculated. The mean and standard deviation of all the terrestrial foodstuffs and aquatic foodstuffs in each year are also calculated and given in the tables.

4.1 Assumptions and Limitations

Two major assumptions are made in the calculation of the mean values of the year. They are :

(a) there exists a static equilibrium between and within the environment and the biosphere, therefore no correction has been made for any possible difference in different food species.

(b) there is no significant regional difference within the small area (at or near Hong Kong) where samples were collected, i.e. there was no localised enhancement or dilution.

The above assumptions are not true in all cases as the isotopic fractionation is slightly different in different species and also a few samples were collected far away from Hong Kong. This would lead to a larger scatter in the sample population. However, the mean values would smooth out the effect of these minor perturbations to give a representative C-14 content in foodstuffs consumed in Hong Kong.

4.2 Halving Time and its Value for the Period 1988 to 1994

The average decline rate of C-14 level is usually expressed as the halving time (T) which is defined as the time the C-14 excess above the naturally produced background declines to half of its original value. Such a definition is analogous with the half life used in radioactive decay.

The halving time between 1988 and 1994 is calculated by taking the average of the four-year period from 1986 to 1989 prior to the operation of the GNPS as the 1988 value, and the average of the three-year period from 1993 to 1995 after the operation of the GNPS as the 1994 value. From the available data, a halving time of 12.7 years for terrestrial foodstuffs consumed in Hong Kong between 1988 and 1994 is obtained. The mathematical expression and detailed calculations for halving time are given in Appendix A.

The calculation is based on the assumptions that there is no significant short term natural fluctuation between the period and that there is no significantly elevated amount of C-14 entering the food chains from the release of the GNPS from 1993 to 1995. The latter is likely to be valid in the light of the results of the measurement programme of the ERMP in those years.

The halving time of 12.7 years within the period 1988 to 1994 is consistent with findings elsewhere. A halving time of about 13 years was used by Otlet et al (1995) for C-14 in atmospheric carbon dioxide between 1985 and 1989.

4.3 Estimation of C-14 contents between 1990 and 1992

By using the halving time of 12.7 years obtained above, the estimated average specific C-14 activity in foodstuffs consumed in Hong Kong between 1990 and 1992 are derived as below :

Year	Average specific C-14 activity (Bq/kg C)	
	Terrestrial foodstuffs	Aquatic foodstuffs
1990	265	254
1991	263	252
1992	261	251

The C-14 content in aquatic foodstuffs is calculated based on the depletion of around 4 percent of C-14 in surface ocean compared with that in the atmosphere. The depletion of C-14 in the surface waters is due to the dilution of C-14 by exchange of deep ocean waters and the isotopic fractionation between air-water boundary.

4.4 Predicted C-14 contents between 1996 and 1998

Using the halving time of 12.7 years, the C-14 contents are extrapolated into the near future to 1998. The predicted average specific C-14 activity in foodstuffs consumed in Hong Kong between 1996 and 1998 are :

Year	Average specific C-14 activity (Bq/kg C)	
	Terrestrial foodstuffs	Aquatic foodstuffs
1996	254	244
1997	252	242
1998	251	241

Such a prediction should be used with caution because of the natural variations of C-14 and the possible localized enhancement from the release of the GNPS. The data should be reviewed regularly when new measurement results are available in the future. However, the predicted values could serve as a rough guidance for analysing the measurement results in the next few years. These values should serve as better

indicators than those obtained in the BRMP to judge any potential increase of C-14 content of the local environment due to the operation of the GNPS.

4.5 Comparison of Derived Values in this Study

Using the halving time of 12.7 years and the two average values of 1988 and 1994, the C-14 contents in foodstuffs consumed in Hong Kong between 1986 and 1995 are calculated. These derived values and the measured values are tabulated in Table 3 and are plotted in Figures 3 and 4. The deviation in the measured values of aquatic foodstuffs is relatively larger than that of the terrestrial foodstuffs. However, since the number of aquatic samples measured between 1993 and 1995 was rather small, the reliance of the average measured values in those years was therefore relatively lower. Moreover, the exchange of C-14 in the aquatic samples with the environment is less well known and likely to be more complicated than in the terrestrial samples. Nevertheless, it is interesting to observe that the average ratio of C-14 in aquatic to terrestrial foodstuffs is 0.96 which is consistent with the ratio of that in surface ocean to the atmosphere.

The derived values in this study are also compared with data obtained elsewhere and are tabulated in Table 4. It is noted that the values in general agree with data obtained worldwide.

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Table 1(a) Specific C-14 Activity (Bq/kg C) of Terrestrial Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational		1993	1994	1995
Beef	China	288 ± 3	267 ± 3	256 ± 3	271 ± 3		n = 4 m = 271 s = 13 R = 256 - 288	262 ± 2		
Pork	China	275 ± 2	270 ± 2	261 ± 3	269 ± 2	n = 4 m = 269 s = 6 R = 261 - 275	n = 8 m = 267 s = 7 R = 255 - 275		254 ± 2	
	Local	273 ± 3	266 ± 2	255 ± 3	270 ± 2	n = 4 m = 266 s = 8 R = 255 - 273		263 ± 2		
Pig's Liver	China	264 ± 2	268 ± 2	259 ± 2		n = 3 m = 264 s = 5 R = 259 - 268	n = 7 m = 267 s = 10 R = 258 - 285			
	Local	285 ± 2	258 ± 2	258 ± 3	275 ± 2	n = 4 m = 269 s = 13 R = 258 - 285				
Chicken	China		271 ± 2	255 ± 3	278 ± 3	n = 3 m = 268 s = 12 R = 255 - 278	n = 6 m = 267 s = 8 R = 255 - 278	261 ± 2		
	Local		266 ± 3	261 ± 3	272 ± 3	n = 3 m = 266 s = 6 R = 261 - 272		258 ± 2	255 ± 2	
Duck	China		269 ± 2	270 ± 3	281 ± 3	n = 3 m = 273 s = 7 R = 269 - 281	n = 7 m = 274 s = 7 R = 263 - 282			267 ± 2
	Local	277 ± 3	273 ± 2	263 ± 3	282 ± 2	n = 4 m = 274 s = 8 R = 263 - 282				

n : number of samples, m : mean, s : standard deviation, R : range

Table 1(b) Specific C-14 Activity (Bq/kg C) of Terrestrial Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational		1993	1994	1995
Chicken's offal	China		272 ± 2			n = 1 m = 272 s = NA R = NA	n = 2 m = 273 s = 1 R = 272 - 274			
	Local		274 ± 2			n = 1 m = 274 s = NA R = NA				
Duck's offal	China		265 ± 2			n = 1 m = 265 s = NA R = NA	n = 2 m = 267 s = 2 R = 265 - 268			
	Local		268 ± 2			n = 1 m = 268 s = NA R = NA				
Rice	China			259 ± 2	264 ± 2		n = 2 m = 262 s = 4 R = 259 - 264	259 ± 2	254 ± 2	255 ± 2
Pasteurized milk	Shenzhen				278 ± 2	n = 1 m = 278 s = NA R = NA	n = 5 m = 281 s = 9 R = 271 - 291		260 ± 2	
	Yuen Long			290 ± 4	271 ± 2	n = 2 m = 281 s = 13 R = 271 - 290				
	Sha Tau Kok			291 ± 3	274 ± 2	n = 2 m = 283 s = 12 R = 274 - 291				256 ± 2
	Fan Ling							259 ± 2		

n : number of samples, m : mean, s : standard deviation, R : range

Table 1(c) Specific C-14 Activity (Bq/kg C) of Terrestrial Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational		1993	1994	1995	
Flowering cabbage	Shenzhen			223 ± 3	270 ± 3	n = 2 m = 247 s = 33 R = 223 - 270	n = 4 m = 259 s = 29 R = 223 - 292	254 ± 2		253 ± 2	
	Local			292 ± 4	251 ± 2	n = 2 m = 272 s = 29 R = 251 - 292					
White cabbage	Shenzhen			238 ± 3	267 ± 2	n = 2 m = 253 s = 21 R = 238 - 267	n = 4 m = 247 s = 20 R = 223 - 267		257 ± 2		
	Local			223 ± 2	259 ± 2	n = 2 m = 241 s = 25 R = 223 - 259					
Banana	China	283 ± 2	265 ± 2	259 ± 2	276 ± 2		n = 4 m = 271 s = 11 R = 259 - 283		254 ± 2	256 ± 2	
Lychee	China		261 ± 2	262 ± 3	280 ± 3		n = 3 m = 268 s = 11 R = 261 - 280				
Mandarin	China			252 ± 3	263 ± 3		n = 2 m = 258 s = 8 R = 252 - 263				
Sugarcane	China			263 ± 3	290 ± 3		n = 2 m = 277 s = 19 R = 263 - 290				
		n = 7 m = 278 s = 8 R = 264 - 288	n = 15 m = 268 s = 4 R = 258 - 274	n = 20 m = 260 s = 18 R = 223 - 292	n = 20 m = 272 s = 9 R = 251 - 290		n = 62 m = 268 s = 13 R = 223 - 292	n = 7 m = 259 s = 3 R = 254 - 263	n = 6 m = 256 s = 2 R = 254 - 260	n = 5 m = 257 s = 6 R = 253 - 267	
		269					257				

n : number of samples, m : mean, s : standard deviation, R : range

Table 2(a) Specific C-14 Activity (Bq/kg C) of Aquatic Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational	1993	1994	1995
Aristichthys nobilis	Shenzhen	268 ± 3	263 ± 2	265 ± 5	265 ± 2	n = 4 m = 265 s = 2 R = 263 - 268	n = 7 m = 267 s = 3 R = 263 - 273	245 ± 2	
	Yuen Long		268 ± 2	273 ± 2	265 ± 2	n = 3 m = 269 s = 4 R = 265 - 273		257 ± 2	245 ± 2
Nemipterus japonicus	Daya Bay	261 ± 2	258 ± 2			n = 2 m = 260 s = 2 R = 258 - 261	n = 10 m = 256 s = 11 R = 227 - 267		
	Daya Bay East	256 ± 2	251 ± 2		263 ± 3	n = 3 m = 257 s = 6 R = 251 - 263			
	H.K. Waters	267 ± 2				n = 1 m = 267 s = NA R = NA			
	H.K. West	259 ± 2	255 ± 2	227 ± 3	261 ± 3	n = 4 m = 251 s = 16 R = 227 - 261			
Trichiurus haumela	Daya Bay	274 ± 2	254 ± 2			n = 2 m = 264 s = 14 R = 254 - 274	n = 10 m = 257 s = 7 R = 248 - 274		
	Daya Bay East	262 ± 3	252 ± 2		255 ± 3	n = 3 m = 256 s = 5 R = 252 - 262			
	H.K. Waters		252 ± 2			n = 1 m = 252 s = NA R = NA			
	H.K. West	263 ± 3	257 ± 2	257 ± 3	248 ± 2	n = 4 m = 256 s = 6 R = 248 - 263			257 ± 2

n : number of samples, m : mean, s : standard deviation, R : range

Table 2(b) Specific C-14 Activity (Bq/kg C) of Aquatic Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational	1993	1994	1995	
Platycephalus indicus	Daya Bay	264 ± 3	255 ± 2	256 ± 2	265 ± 2	n = 4 m = 260 s = 5 R = 255 - 265	n = 11 m = 257 s = 11 R = 235 - 273			
	Daya Bay East	266 ± 2		235 ± 4		n = 2 m = 251 s = 22 R = 235 - 266				
	H.K. Waters		251 ± 2	268 ± 4	248 ± 3	n = 3 m = 256 s = 11 R = 248 - 268				
	H.K. West	273 ± 3		248 ± 3		n = 2 m = 261 s = 18 R = 248 - 273				
Portunus sanguinolentus (crab)	Daya Bay		255 ± 2	224 ± 2	266 ± 2	n = 3 m = 248 s = 22 R = 224 - 266	n = 9 m = 247 s = 17 R = 224 - 266			
	Daya Bay East			253 ± 2		n = 1 m = 253 s = NA R = NA				
	H.K. Waters		264 ± 2	225 ± 3	257 ± 3	n = 3 m = 249 s = 21 R = 225 - 264				
	H.K. West		256 ± 2	225 ± 2		n = 2 m = 241 s = 22 R = 225 - 256		255 ± 2		

n : number of samples, m : mean, s : standard deviation, R : range

Table 2(c) Specific C-14 Activity (Bq/kg C) of Aquatic Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational	1993	1994	1995
Metapenaeopsis barbata (shrimp)	Daya Bay	253 ± 3	262 ± 2	223 ± 2	268 ± 2	n = 4 m = 252 s = 20 R = 223 - 268	n = 12 m = 254 s = 18 R = 221 - 279		
	Daya Bay East	267 ± 2	258 ± 2	233 ± 4		n = 3 m = 253 s = 18 R = 233 - 267			
	H.K. Waters		259 ± 2		260 ± 2	n = 2 m = 260 s = 1 R = 259 - 260			
	H.K. West	260 ± 3	279 ± 2	221 ± 2		n = 3 m = 253 s = 30 R = 221 - 279			
Loligo edulis (squid)	Daya Bay	263 ± 2	261 ± 2	223 ± 2	262 ± 2	n = 4 m = 252 s = 20 R = 223 - 263	n = 13 m = 255 s = 20 R = 223 - 296		
	Daya Bay East		258 ± 2		260 ± 2	n = 2 m = 259 s = 1 R = 258 - 260			
	H.K. Waters		244 ± 2	231 ± 2	257 ± 2	n = 3 m = 244 s = 13 R = 231 - 257			
	H.K. West	263 ± 2	270 ± 2	226 ± 2	296 ± 2	n = 4 m = 264 s = 29 R = 226 - 296			253 ± 2

n : number of samples, m : mean, s : standard deviation, R : range

Table 2(d) Specific C-14 Activity (Bq/kg C) of Aquatic Foodstuffs Consumed in Hong Kong

Sample	Location	1986	1987	1988	1989	Pre-operational		1993	1994	
Tapes philipinarum	Cheung Chau	253 ± 2	254 ± 2		254 ± 2	n = 3 m = 254 s = 1 R = 253 - 254	n = 10 m = 255 s = 6 R = 244 - 267			
	Port Shelter	256 ± 2	261 ± 2	244 ± 2	250 ± 2	n = 4 m = 253 s = 7 R = 244 - 261				
	Tolo		256 ± 2	256 ± 2	267 ± 3	n = 3 m = 269 s = 6 R = 256 - 267				
Perna viridis	Cheung Chau	264 ± 2	257 ± 2	223 ± 2	259 ± 2	n = 4 m = 251 s = 19 R = 223 - 264	n = 12 m = 255 s = 16 R = 223 - 274		249 ± 2	
	Junk Bay	266 ± 3	247 ± 2	226 ± 2	255 ± 3	n = 4 m = 249 s = 17 R = 226 - 266				
	Tolo	259 ± 2	274 ± 2	264 ± 3	264 ± 3	n = 4 m = 265 s = 6 R = 259 - 274				
Babylonia formosae	Castle Peak Bay	259 ± 2	255 ± 2			n = 2 m = 257 s = 3 R = 255 - 259	n = 6 m = 257 s = 3 R = 255 - 263			
	Mirs Bay	263 ± 2	255 ± 2	256 ± 4	255 ± 3	n = 4 m = 257 s = 4 R = 255 - 263				
		n = 23 m = 263 s = 5 R = 253 - 274	n = 30 m = 258 s = 7 R = 244 - 279	n = 24 m = 241 s = 17 R = 221 - 273	n = 23 m = 261 s = 10 R = 248 - 296		n = 100 m = 256 s = 14 R = 221 - 296	n = 2 m = 256 s = 1 R = 255 - 257	n = 2 m = 247 s = 3 R = 245 - 249	n = 3 m = 252 s = 6 R = 245 - 257
		256						252		

n : number of samples, m : mean, s : standard deviation, R : range

Table 3 Comparison of Derived and Measured Specific C-14 Activity (Bq/kg C) of Foodstuffs Consumed in Hong Kong

Year	Terrestrial foodstuffs			Aquatic foodstuffs			Ratio of Aquatic to Terrestrial Foodstuffs (measured values)
	Derived values	Measured values †	Difference (%)	Derived values	Measured values †	Difference (%)	
1986	274	278 ± 8 (7)	+ 2	263	263 ± 5 (23)	0	0.95
1987	271	268 ± 4 (15)	- 1	260	258 ± 7 (30)	- 1	0.96
1988	269	260 ± 18 (20)	- 3	258	241 ± 17 (24)	- 7	0.93
1989	267	272 ± 9 (20)	+ 2	256	261 ± 10 (23)	+ 2	0.96
1990	265			254			
1991	263			252			
1992	261			251			
1993	259	259 ± 3 (7)	0	249	256 ± 1 (2)	+ 3	0.99
1994	257	256 ± 2 (6)	- 0	247	247 ± 3 (2)	0	0.96
1995	255	257 ± 6 (5)	+ 1	245	252 ± 6 (3)	+ 3	0.98
1996	254			244			
1997	252			242			
1998	251			241			
						Average	0.96

† The one standard deviation of the sample population is given and the number of samples is enclosed in bracket

Table 4 Comparison of Derived Values of Specific C-14 Activity (Bq/kg C) of Terrestrial Foodstuffs Consumed in Hong Kong with Data Obtained Elsewhere

Year	Derived Values in Hong Kong	Derived Values in U.K. (Otlet et al, 1995)	U.K. Environmental Measurements (Otlet et al, 1995)	Georgian Wine (Burchuladze et al, 1989)	USA Milk (Moore et al, 1993)	N. Hemisphere CO ₂ † (Levin et al, 1992)	S. Hemisphere CO ₂ (Manning et al, 1990)
1986	274	277		269	273		270
1987	271	273		264	267	267	268
1988	269	269				264	
1989	267	266				262	
1990	265	263					
1991	263	261	259				
1992	261	259	258				
1993	259	257	259				
1994	257	256	255				
1995	255	254					

† The data are derived values from data published in graphical but not numerical form

Figure 1 : C-14 Concentration of Tropospheric CO₂ between 1959 and 1979 (reproduced from Levin, et al 1980)

The lower curve represents the C-14 concentration in the southern hemisphere (Pretoria and Bariloche, South Africa and the upper one shows the time variation in the northern hemisphere (Trapani, Schleswig, Vermont and Schauinsland, Western Europe).

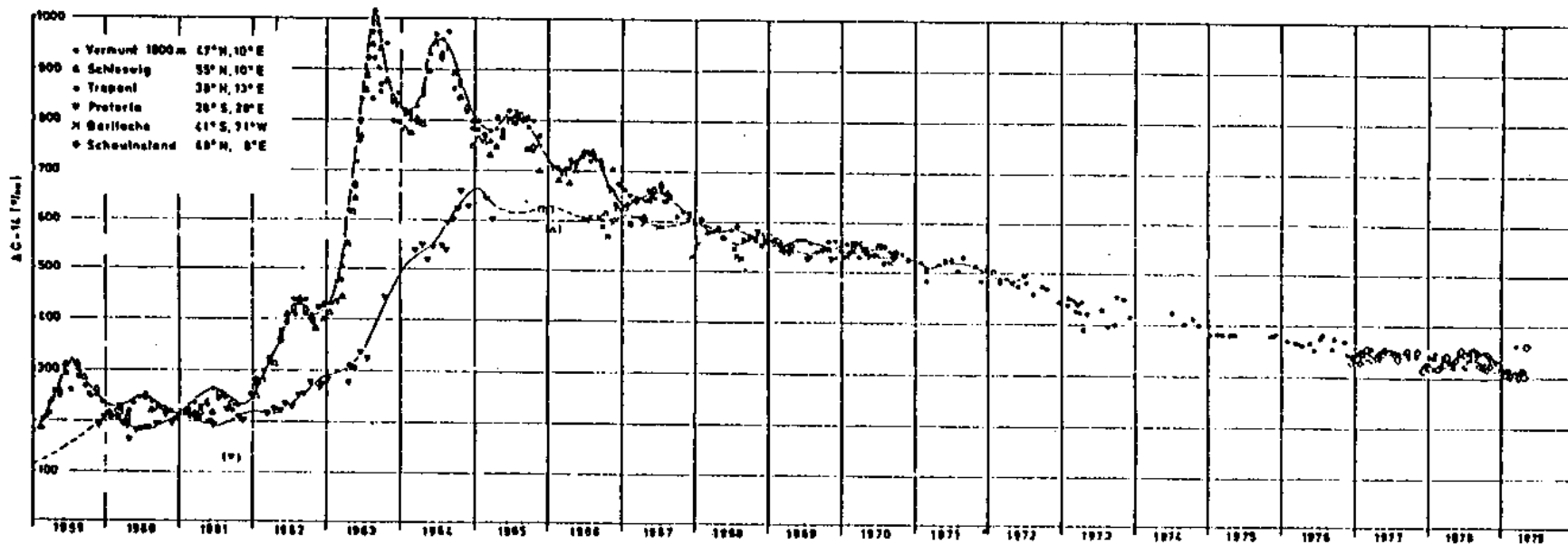
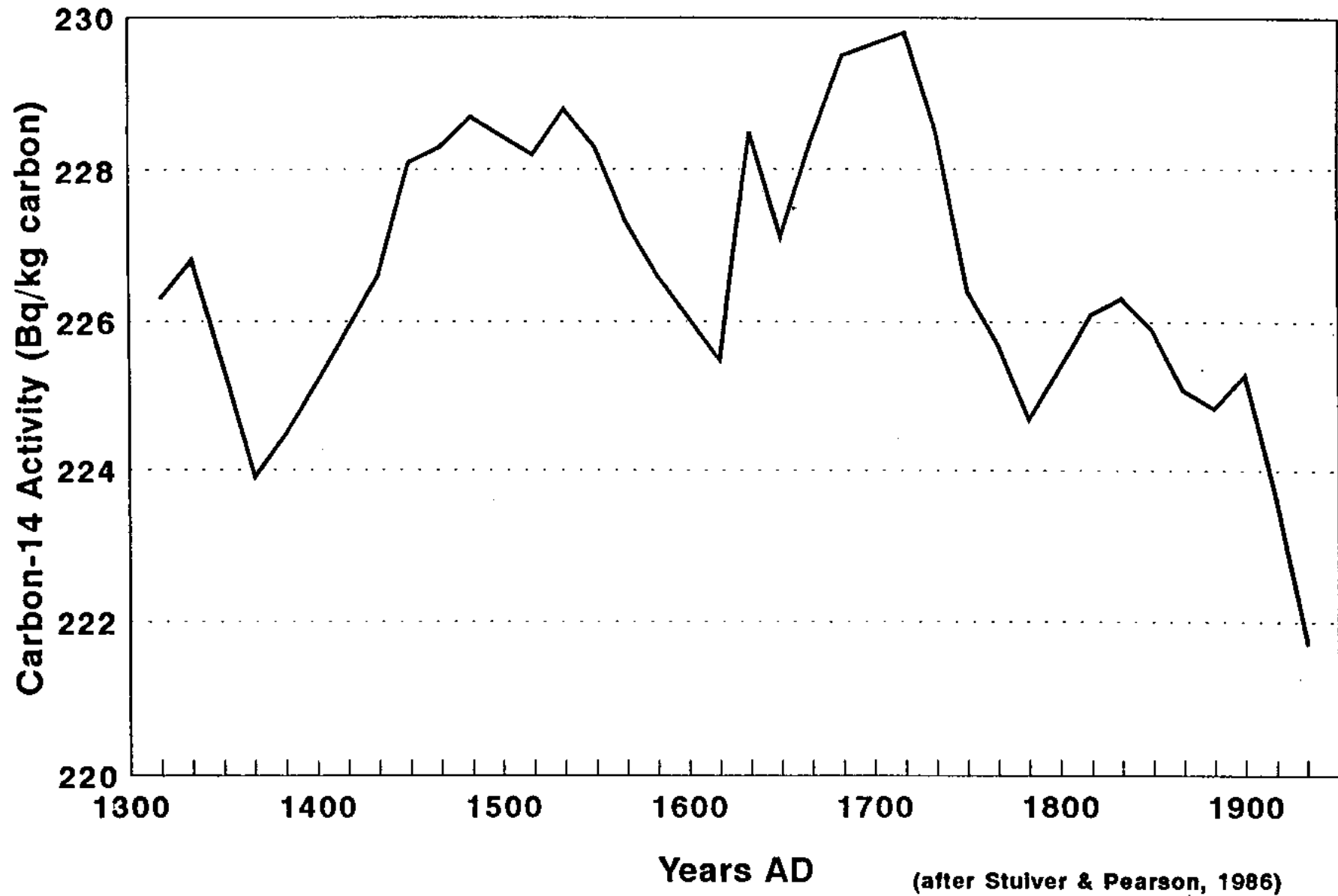
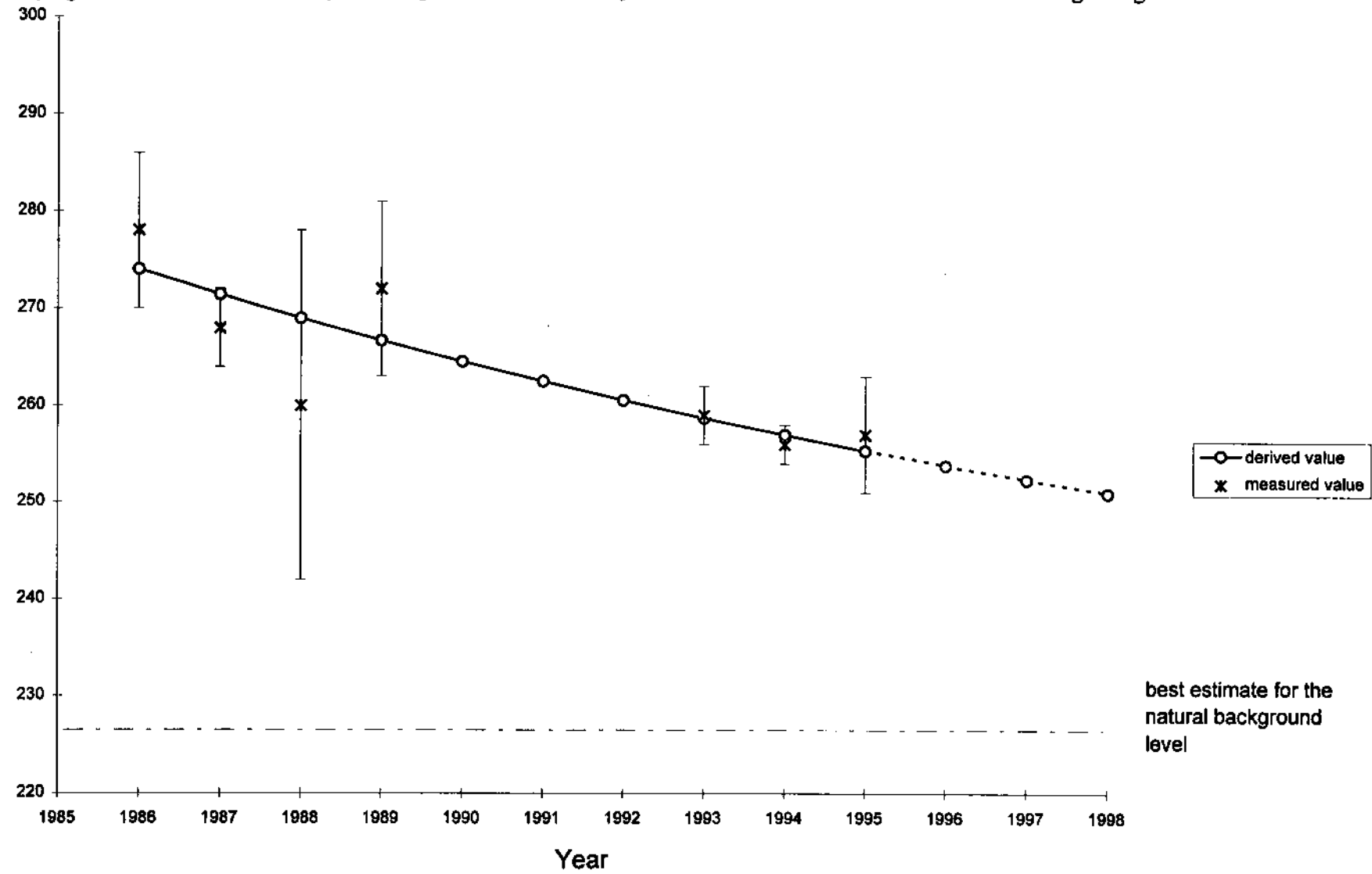


Figure 2 : Reconstruction of Background Levels of C-14 from AD1300 to AD1950
(reproduced from Olet, et al 1995)



Bq/Kg C

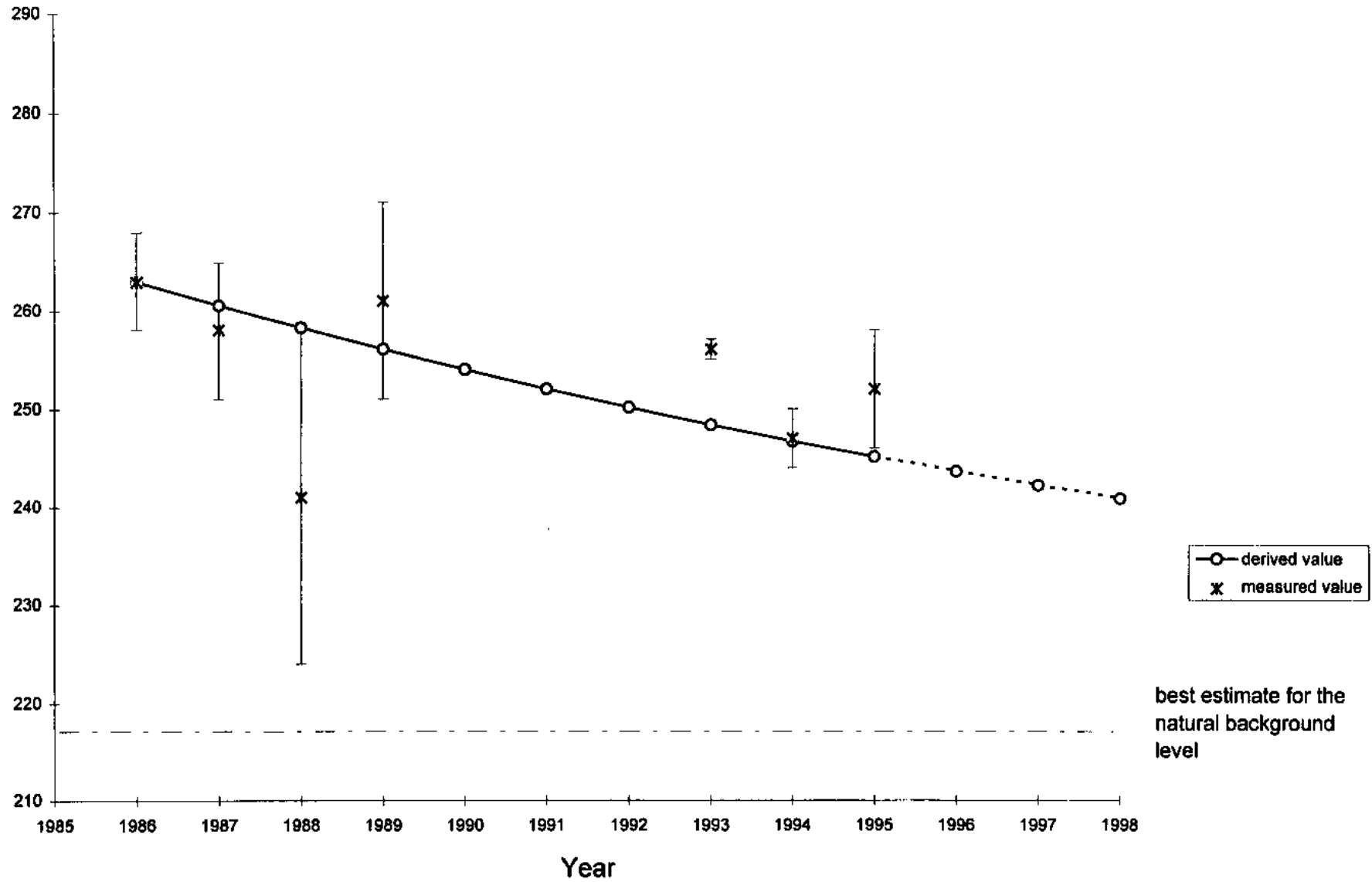
Figure 3 : Specific C-14 Activity of Terrestrial Foodstuffs Consumed in Hong Kong



best estimate for the natural background level

Bq/Kg C

Figure 4 : Specific C-14 Activity of Aquatic Foodstuffs Consumed in Hong Kong



Appendix A - Calculations of Halving Time

The average decline rate of C-14 level is usually expressed as the halving time (T) which is defined as the time the C-14 excess above the naturally produced background declines to half of its original value. Such a definition is analogous with the half life used in radioactive decay.

One obtains

$$(A_t - A_b) = (A_0 - A_b) \exp(-\ln 2 \times t / T)$$

where A_0 , A_t and A_b are the specific C-14 activity at time=0, time=t and the naturally produced background level respectively.

Therefore,

$$T = (\ln 2 \times t) / \ln[(A_0 - A_b)/(A_t - A_b)]$$

The best estimate of A_b is 226 Bq/kg C for the natural, cosmogenically produced background level.

In this study, the halving time between 1988 and 1994 is

$$\begin{aligned} T(88 \text{ to } 94) &= (\ln 2 \times 6) / \ln[(269-226)/(257-226)] \\ &= 12.7 \text{ years} \end{aligned}$$