加速器質譜碳十四定年及其應用

AMS ^{14}C dating and its applications

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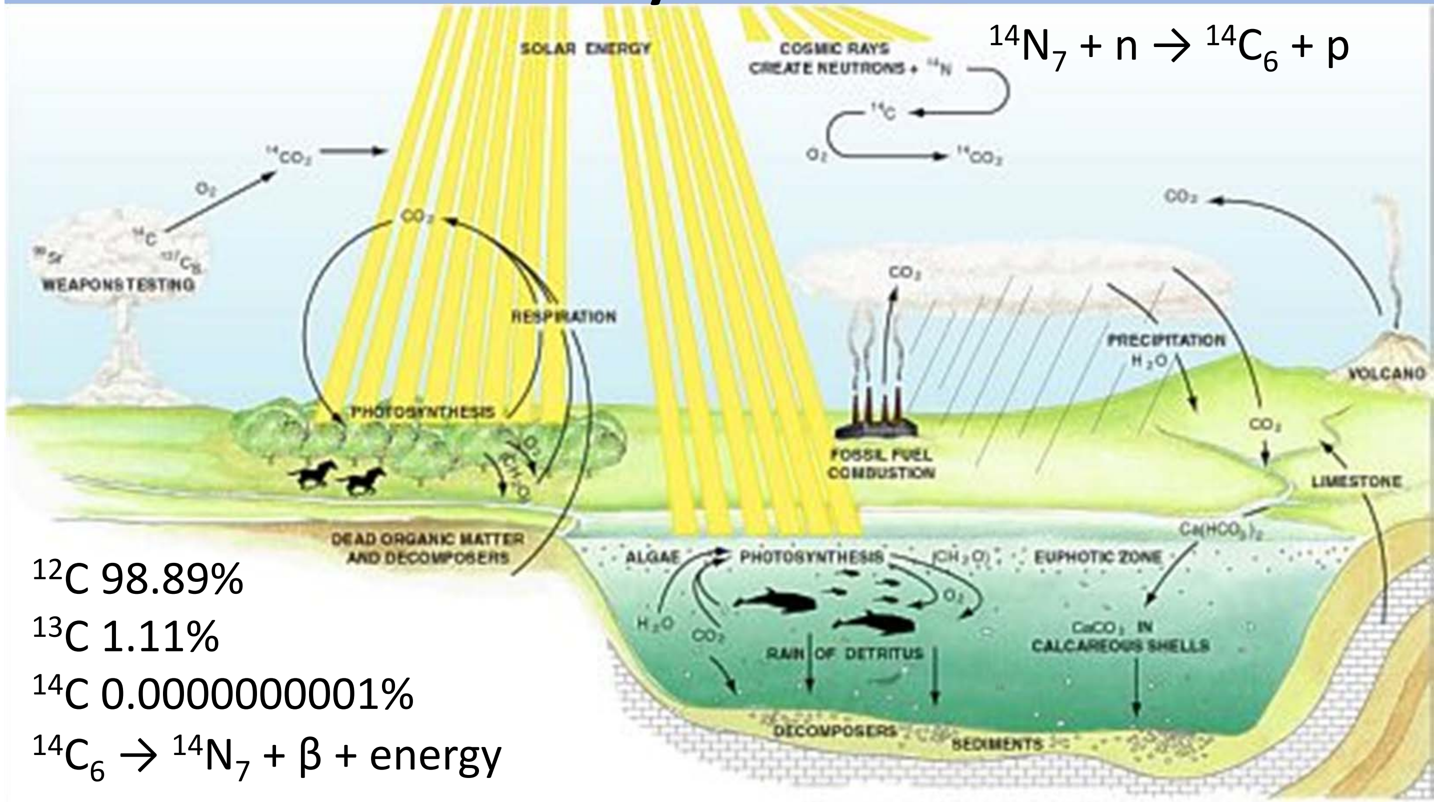
內容提要

- 碳十四定年原理
- 加速器質譜測量
- **The NTUAMS Lab**
- **STD, BKG & Calibration**
- **Applications**
- **Summary**

Cosmic ray



$^{14}N_7 + n \rightarrow {}^{14}C_6 + p$

^{12}C 98.89%
^{13}C 1.11%
^{14}C 0.0000000001%
$^{14}C_6 \rightarrow {}^{14}N_7 + \beta$ + energy

Willard Frank Libby
(1908~80)

Established ^{14}C dating method in 1949

Since 1950

Gas Proportional Counting (**GPC**)
Liquid Scintillation Counting (**LSC**)

Since 1977

Accelerator Mass Spectrometry (**AMS**)

Half life = 5730±40 yrs

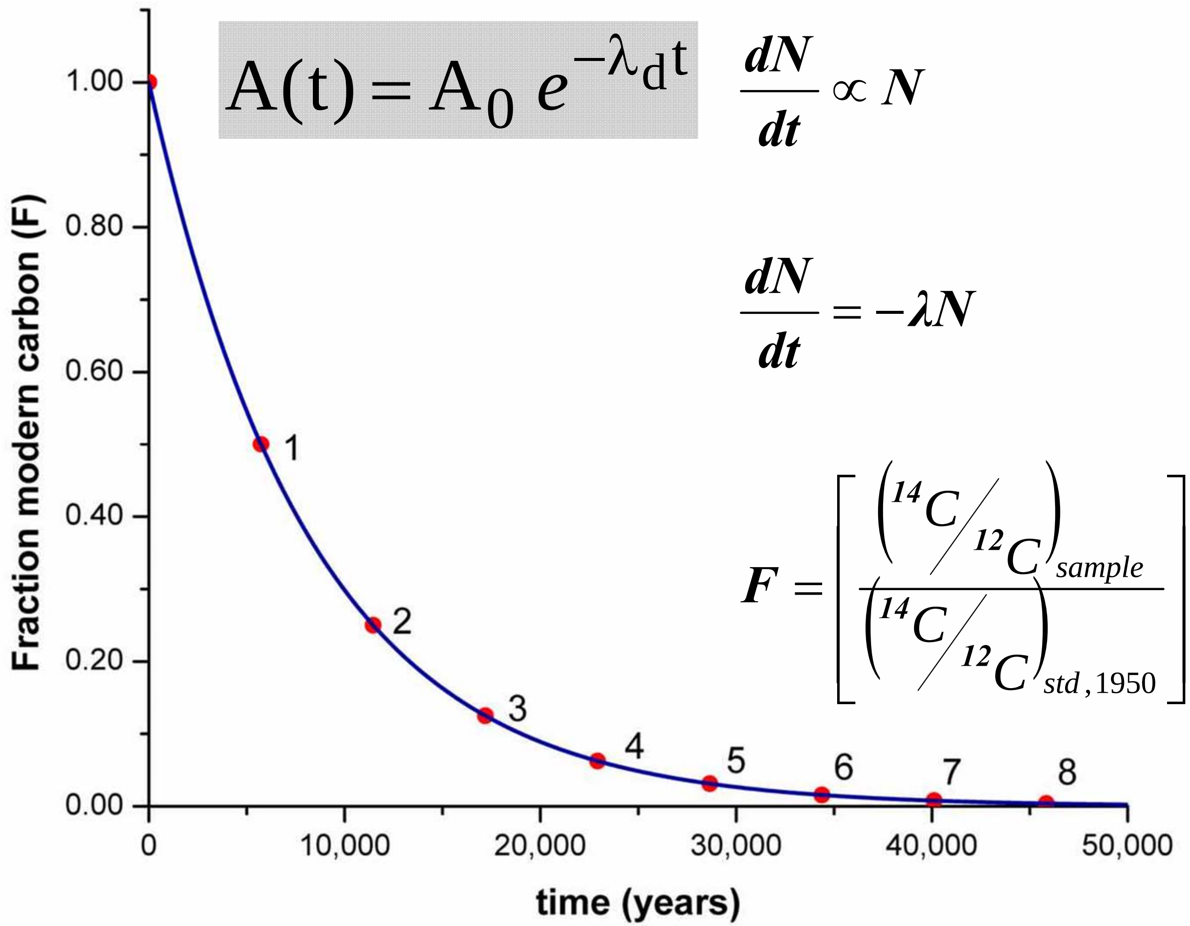
Current AMS dating range: 10 ~ 55,000 years

With 0.3% (±30 years) precision

Sample size can be as small as 30 μgC

Production rate can be 500 samples/month

碳十四定年法



$$A(t) = A_0\, e^{-\lambda_d t}$$

$$\frac{dN}{dt} \propto N$$

$$\frac{dN}{dt} = -\lambda N$$

$$F = \left[\frac{\left({}^{14}C / {}^{12}C \right)_{sample}}{\left({}^{14}C / {}^{12}C \right)_{std,1950}} \right]$$

Age (years BP) = -8033 lnF

1. Initial $^{14}C/^{12}C$ ratio problems: natural variation and human impact—fossil fuel and nuclear bomb.

2. Sample contamination: modern C and old carbon.

3. Age representative: component and depositional time.

常規測量 vs. AMS 測量

β 衰變（decay）

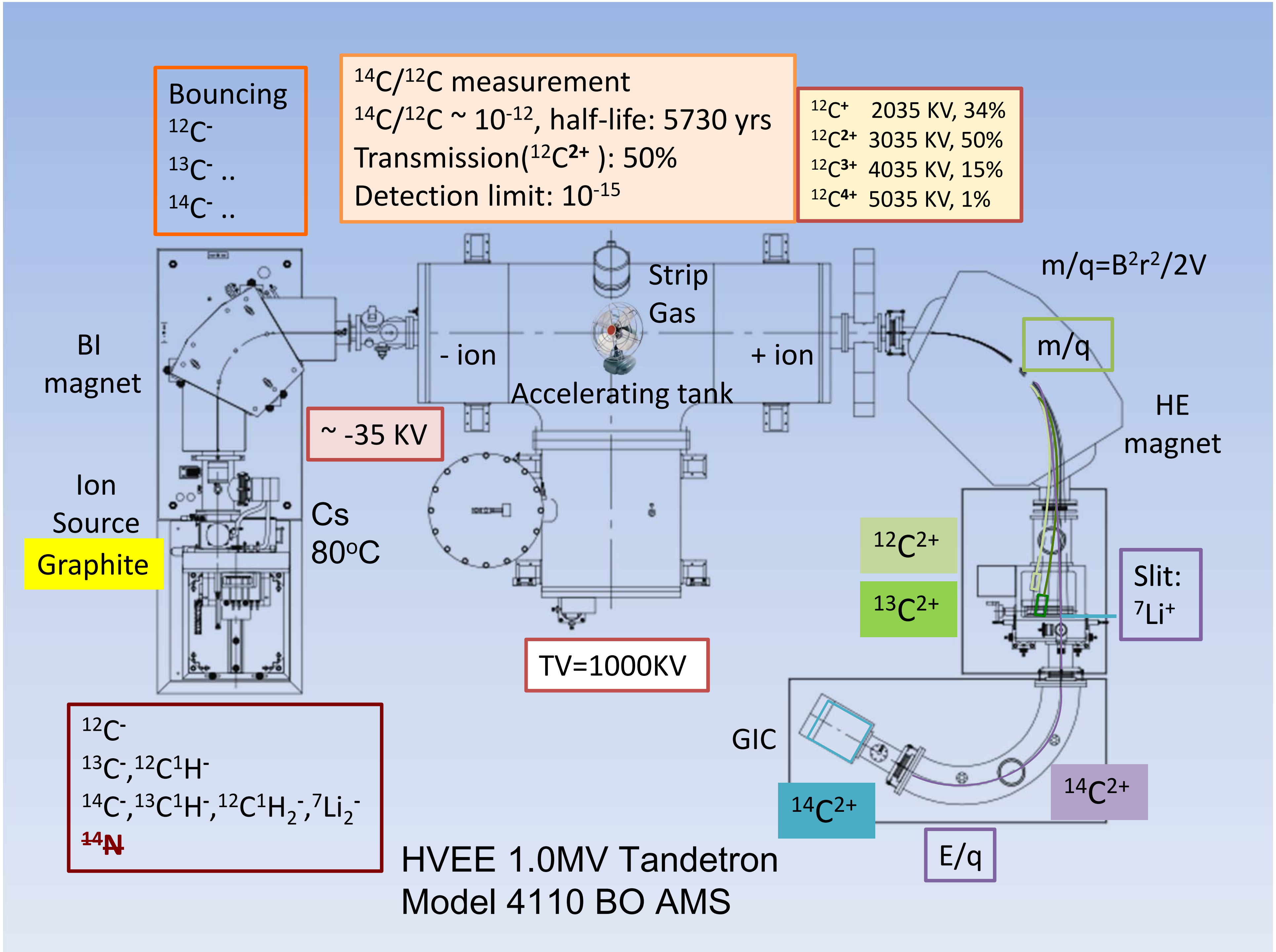
1. 樣品量大（大於**0.5**克碳）
2. 測量時間長（超過**1**天）
3. 精度差（一般不到**1%**）
4. 測年範圍窄（幾百年~**4**萬年）

直接計數^{14}C粒子

1. 樣品量小（**1**毫克碳）
2. 測量時間短（約**1~2**小時）
3. 精度高（大約**0.3%**）
4. 測年範圍廣（**10**年~**5**萬年）

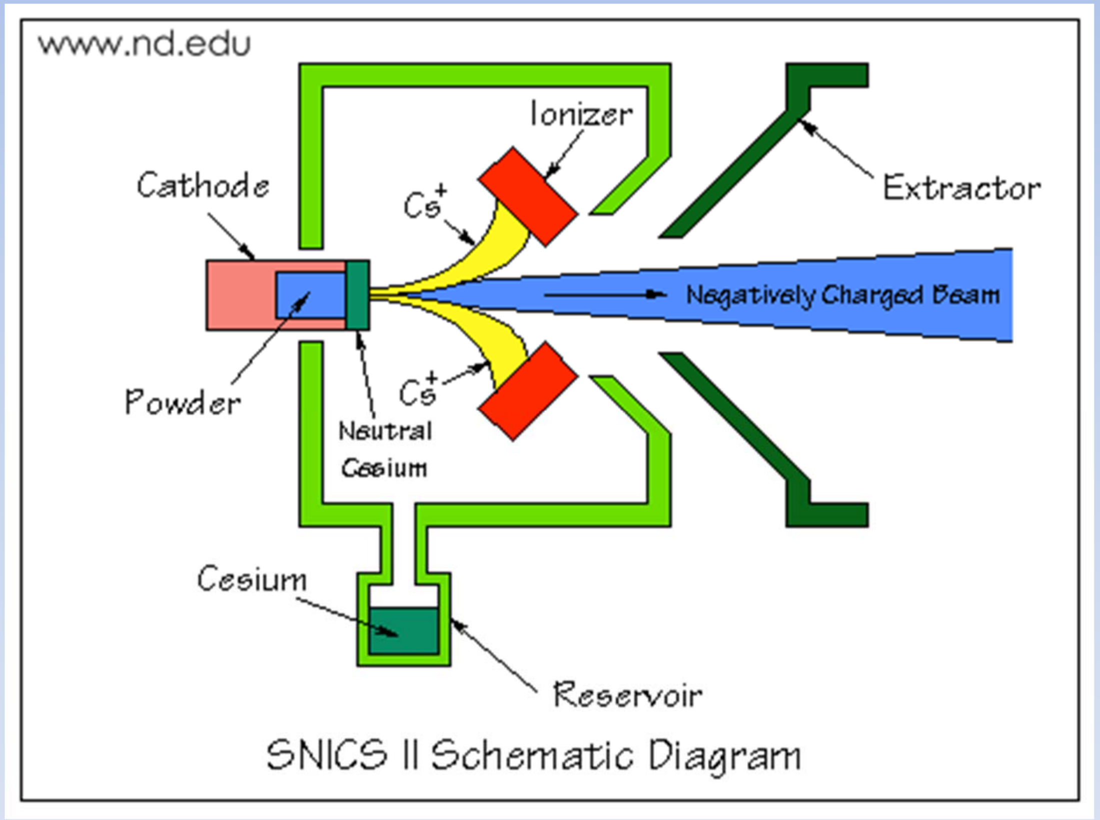
AMS探測的豐度靈敏度在10^{-12}～10^{-15}範圍，即能在千億個原子中把含量只有一個的放射性核素原子探測到

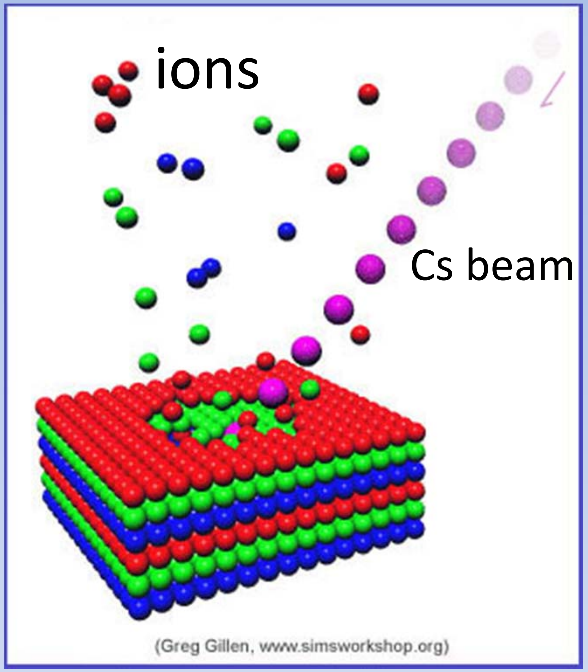
HVEE 1MV Tandetron AMS


Bouncing
$^{12}C^-$
$^{13}C^-$ ..
$^{14}C^-$ ..
$^{14}C/^{12}C$ measurement
$^{14}C/^{12}C \sim 10^{-12}$, half-life: 5730 yrs
Transmission($^{12}C^{2+}$): 50%
Detection limit: 10^{-15}
$^{12}C^{+}$ 2035 KV, 34%
$^{12}C^{2+}$ 3035 KV, 50%
$^{12}C^{3+}$ 4035 KV, 15%
$^{12}C^{4+}$ 5035 KV, 1%
BI magnet
Strip Gas
- ion
+ ion
Accelerating tank
$m/q=B^2r^2/2V$
m/q
HE magnet
~ -35 KV
Ion Source
Graphite
Cs
80^oC
$^{12}C^{2+}$
$^{13}C^{2+}$
Slit: $^7Li^+$
TV=1000KV
GIC
$^{14}C^{2+}$
$^{14}C^{2+}$
E/q
$^{12}C^-$
$^{13}C^-$,$^{12}C^1H^-$
$^{14}C^-$,$^{13}C^1H^-$,$^{12}C^1H_2^-$,$^7Li_2^-$
~~^{14}N~~
HVEE 1.0MV Tandetron
Model 4110 BO AMS

Ion Source

銫濺射固體(石墨)離子源

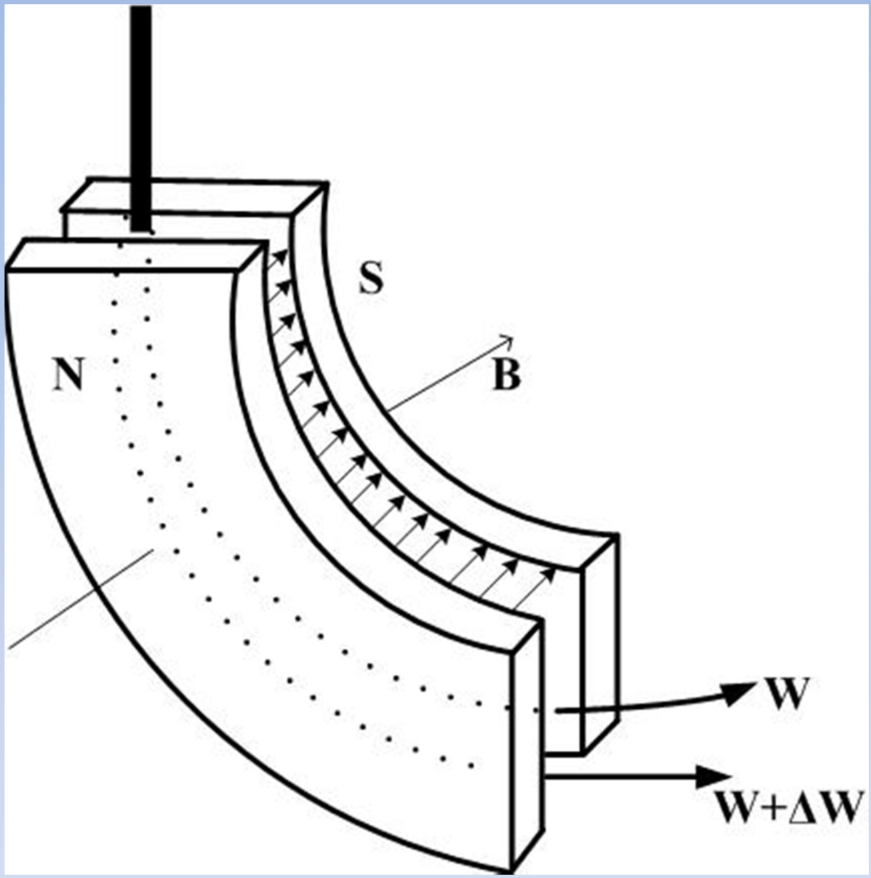




Clean up ion source

被氧化的銫

質譜儀特性



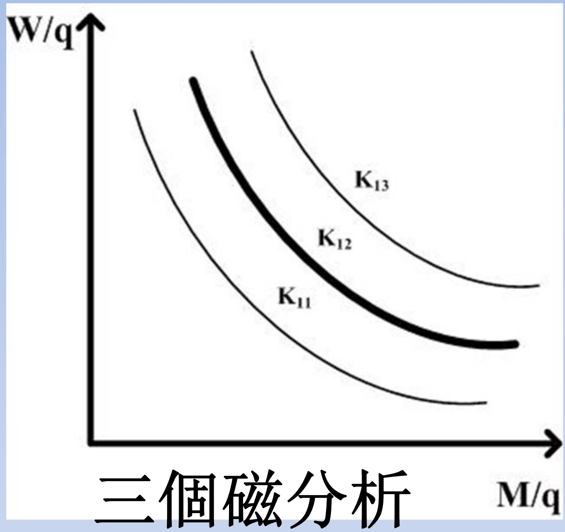
$$\begin{cases} qvB = \dfrac{Mv^2}{r} \\ \dfrac{1}{2}Mv^2 = W \qquad v = \sqrt{\dfrac{2W}{M}} \\ P = Mv = \sqrt{2WM} \end{cases}$$

$$Br = \frac{P}{q}$$

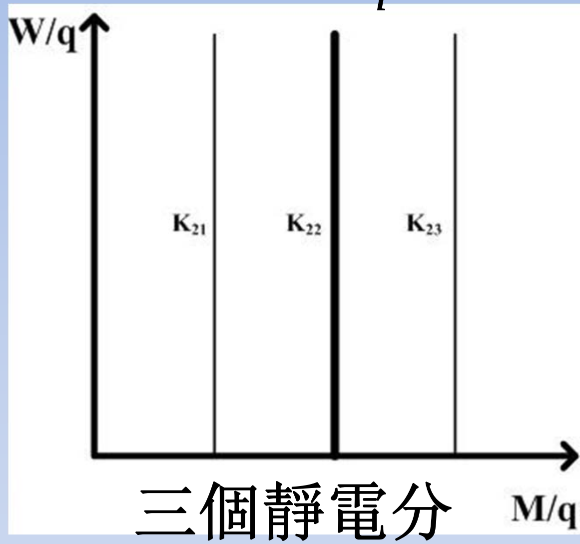
$$K_1 = (Br)^2 \sim \frac{WM}{q^2} = \left(\frac{W}{q}\right)\left(\frac{M}{q}\right)$$

特性：磁鐵中不同品質的粒子只要它們動量相同就能通過同一中心軌跡。(如果 它們能量相同，是無法通過同一中心軌跡。)

MS必須有兩種不同類型的分析器的組合，才能鑒別粒子的物理特性：$\frac{W}{q}$ 和 $\frac{M}{q}$

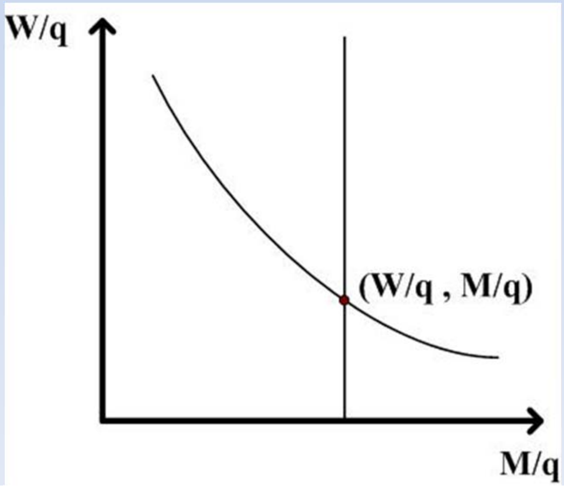


三個磁分析器組合



三個靜電分析器組合

而不同質量的帶電粒子有不同的轉彎半徑，只有轉彎半徑一致的粒子通過磁鐵，而其他粒子就被過濾掉



磁分析器和靜電分析器組合

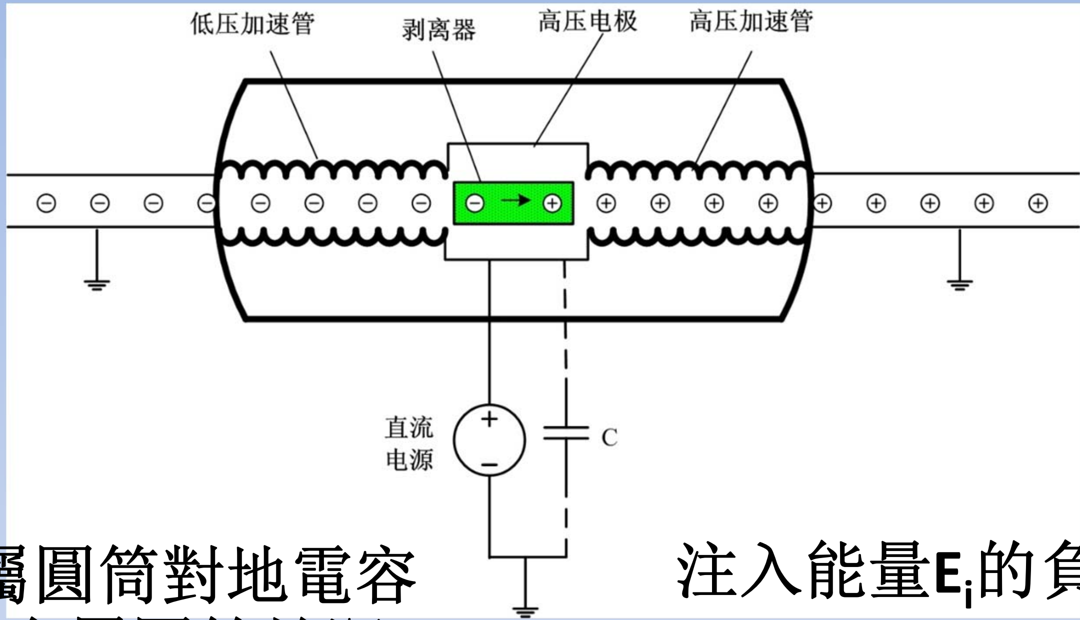
質譜儀鑒別的粒子的 $\frac{W}{q}$ 和 $\frac{M}{q}$

不是唯一的 $$\frac{W}{q}=\frac{nW}{nq} \qquad \frac{M}{q}=\frac{nM}{nq}$$

被鑒別離子	分子本底
$^{14}C^{-}$	$^{13}CH^{-}$
$^{14}C^{-}$	$^{12}CH_2{}^{-}$
$^{14}C^{++}$	$^{7}Li_2{}^{+}$
$^{14}C^{+}$	$^{12}CH_2{}^{+}$
$^{14}C^{+}$	$^{13}CH^{+}$
$^{14}C^{+}$	$^{12}C^{16}O^{2+}$
$^{14}C^{+}$	$^{12}C^{12}CH_4{}^{2+}$

因此，只要是質量與電荷比相近的粒子均能穿過磁場，這就是爲什麼需要加速器，來測不同電價的粒子，即第三步除幹擾

高壓加速原理



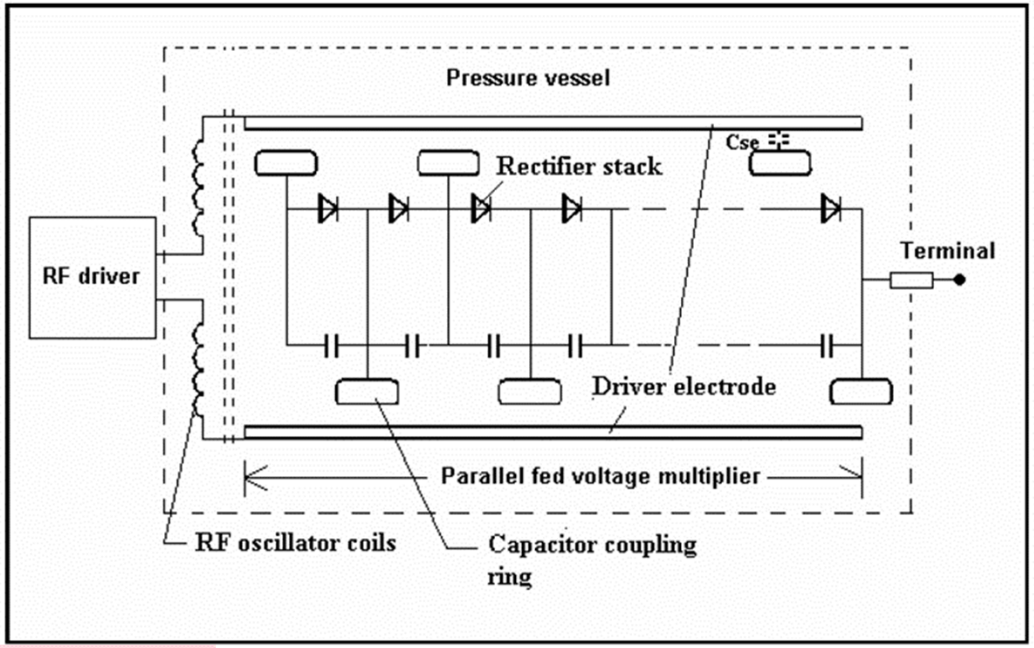
一個空心金屬圓筒對地電容為**C**，連續向金屬圓筒輸運電荷**Q**，金屬圓筒上就有高電壓**V＝Q/C**（高壓電極），高壓電極兩端分別接一根真空加速管，內部有剝離器。

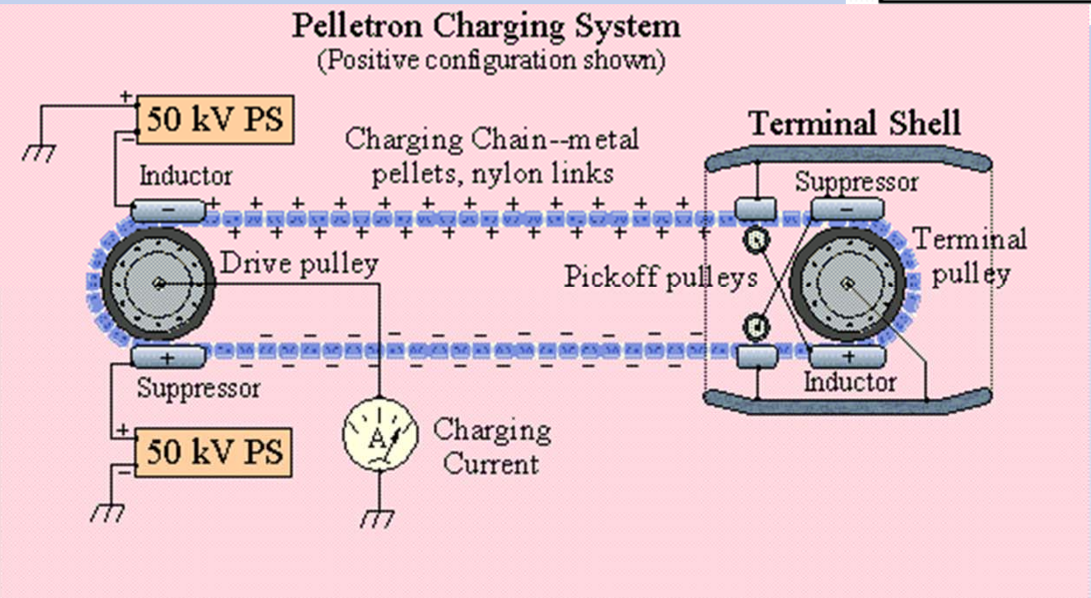
注入能量E_i的負離子由地電位加速到高壓電極，能量增加**Vq**，經剝離後變帶**n**個電荷的正離子，由高壓電極加速到地，能量增加**nqV**。

$$E_i + Vq + nqV = E_i + (1+n)qV$$

兩種高壓電源加壓方式

為了得到高的三價離子產額$^{14}C^{3+}$（最佳平衡電荷態），入射離子能量應在2.5～2.7MV。

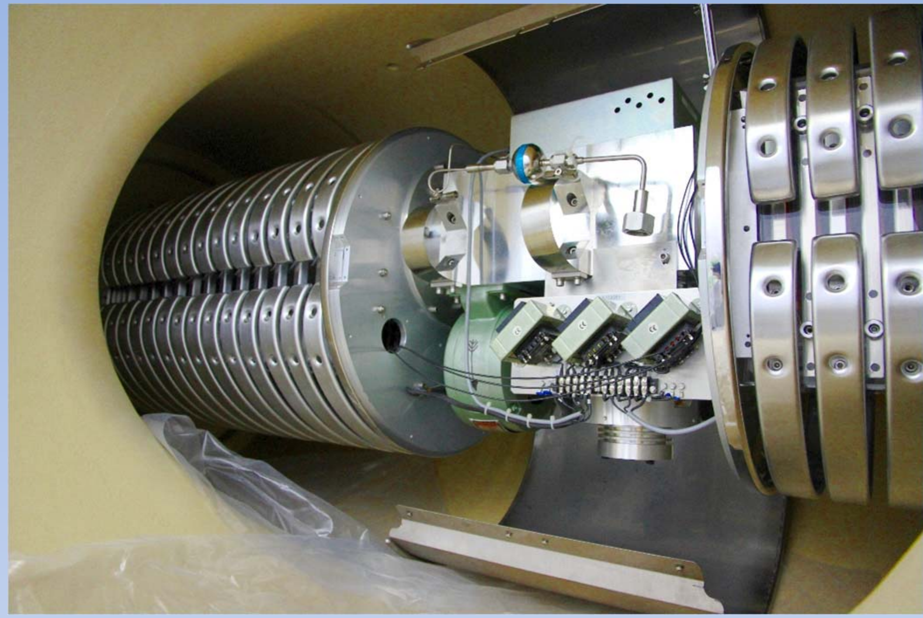




HVEE Tandtron　高頻高壓電源

為了得到3MV端電壓，商品化的設備有兩種向高壓電極輸送電荷的模式。

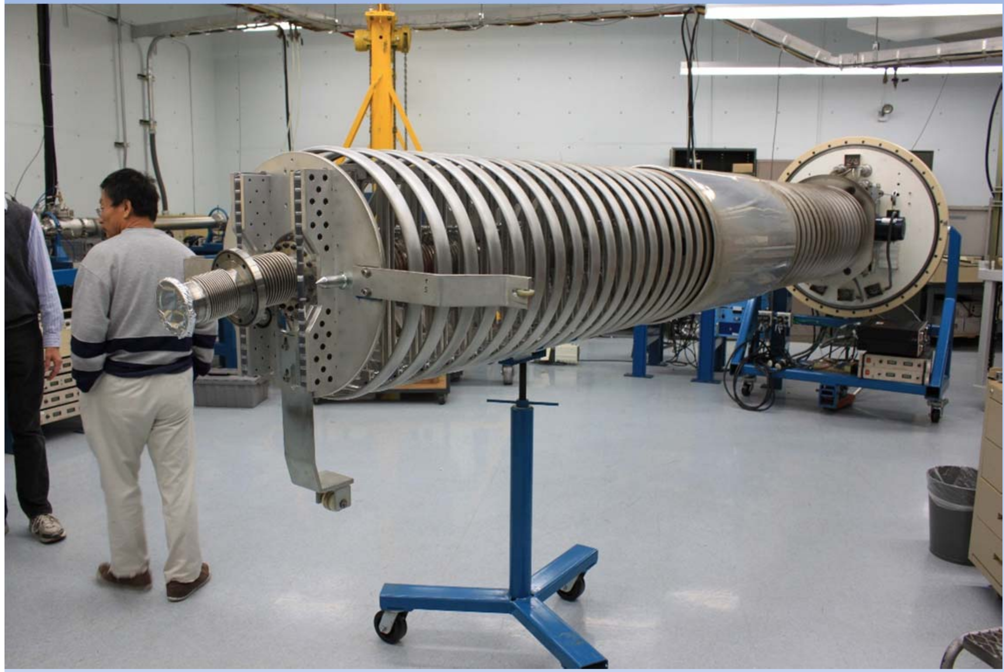
NEC Pelletron　輸電鏈

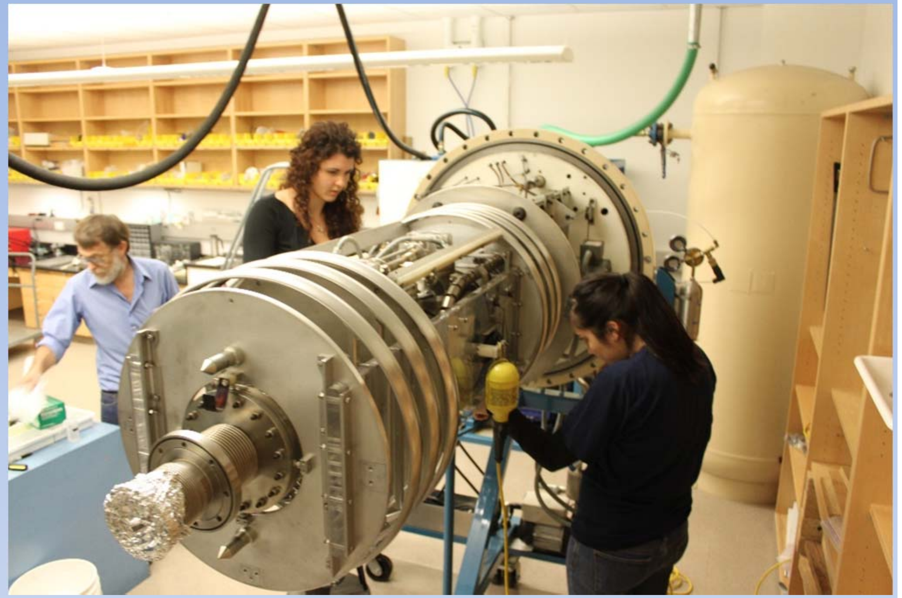


HVEE Tandtron

AZU 5MV NECAMS

UCI 0.5MV NEC AMS





西安中科院地環所HVE 3.0MV AMS

Final acceptance test for ^{14}C

The targets from HVE were made by Oxford Lab

41256	Taipei	B7874

REFERENCE SAMPLES — OXII

measured ratio	C14/C12
stated value	1.575E-12
required precision (‰)	5
total counts per sample	40000

Each target was measured three times, and each time the counts are greater than 40,000.

BACKGROUND SAMPLE

measured ratio	C14/C12
stated value	3E-15
required value	3E-15
counts/time	1 hour

cycle number	sample name/position #13	#14	#15	#16	mean of cycle	relative sd of cycle (‰)	se of cycle (‰)
1	1.41149E-12	1.39705E-12	1.40594E-12	1.39745E-12	1.40298E-12	4.99	4.88
2	1.42176E-12	1.41543E-12	1.42141E-12	1.41693E-12	1.41888E-12	2.24	4.94
3	1.41925E-12	1.41776E-12	1.42070E-12	1.41299E-12	1.41768E-12	2.36	4.89
mean of sample	1.41750E-12	1.41008E-12	1.41602E-12	1.40912E-12	1.41318E-12		
relative sd of sample (‰)	3.78	8.05	6.17	7.31			
se of sample (‰)	4.89	4.93	4.87	4.93			

	relative sd (‰)	se (‰)	
all measurements	6.18	4.90	
over samples	2.97	2.83	= precision PASSED
over cycles	6.26	2.45	

correction factor: 1.115

sample name/position	12
measured value	2.46582E-15
corrected value	2.74818E-15

= background PASSED
= -48665 years in case of c

Check the following:
Measured ratios should not deviate too much from the stated value (in case no foils are used). Note: correction factor must be > 1.
Relative standard deviation (sd) values should be around their corresponding mean statistical error (se) values.
The trend in the values of the column 'mean of cycle' is 5.2 ‰/cycle. Is current correction necessary?

No sample deviates more than 3 standard deviations from the mean of the other 3 samples.

exceptional event box

Final acceptance test for ^{10}Be

40919	NTU Taipei	B7874

REFERENCE SAMPLES

current corrected ratio	Be10/Be9
stated value	2.79E-11
required precision (‰)	30
total counts per sample	1112

BACKGROUND SAMPLE

current corrected ratio	Be10/Be9
stated value	3E-14
required value	3E-14
counts/time	1 hour

cycle number	sample name/position				mean of cycle	relative sd of cycle (‰)	se of cycle (‰)
	19 Berylium re	20 Berylium re	21 Berylium re	22 Berylium re			
1	1.55734E-12	1.43482E-12	1.43972E-12	1.47748E-12	1.47734E-12	38.34	28.46
2	1.57245E-12	1.50273E-12	1.49718E-12	1.43805E-12	1.50260E-12	36.60	28.64
3	1.52845E-12	1.50318E-12	1.41500E-12	1.53844E-12	1.49627E-12	37.54	28.93
4	1.53872E-12	1.50754E-12	1.53212E-12	1.47315E-12	1.51288E-12	19.63	28.46
5	1.51990E-12	1.54196E-12	1.43662E-12	1.44595E-12	1.48611E-12	35.44	28.46
6	1.48915E-12	1.50236E-12	1.46401E-12	1.52588E-12	1.49535E-12	17.27	28.81
7	1.40984E-12	1.49925E-12	1.46331E-12	1.43600E-12	1.45210E-12	26.36	29.08
8	1.39496E-12	1.46460E-12	1.50946E-12	1.41537E-12	1.44610E-12	35.52	28.95
9	1.46799E-12	1.53555E-12	1.49371E-12	1.47767E-12	1.49373E-12	19.97	28.39
10	1.45383E-12	1.54515E-12	1.46167E-12	1.44369E-12	1.47608E-12	31.59	29.08
mean of sample	1.49326E-12	1.50371E-12	1.47128E-12	1.46717E-12	1.48386E-12		
relative sd of sample (‰)	40.69	22.72	24.72	27.15			
se of sample (‰)	28.53	28.79	28.63	28.95			

	relative sd (‰)	se (‰)	
all measurements	30.35	28.72	
over samples	11.80	9.08	= precision PASSED
over cycles	14.42	14.36	

sample name/position	Pos #35 Be Bg
current corrected value	9.04127E-16
correction factor	18.802
corrected value	1.69997E-14 = background PASSED

Check the following:

Corrected ratios should not deviate too much from the stated value (in case no foils are used). Note: correction factor must be > 1.

Relative standard deviation (sd) values should be around their corresponding mean statistical error (se) values.

The trend in the values of the column 'mean of cycle' is -2.03 ‰/cycle.

No sample deviates more than 3 standard deviations from the mean of the other 3 samples.

exceptional event box

Final acceptance test for ^{26}Al

41260 NTU Taipei B7874 Onsite

REFERENCE SAMPLES

measured ratio	Al26/Al27
stated value	9.35E-11
required precision (‰)	30
total counts per sample	1112

cycle number	sample name/position				mean of cycle	relative sd of cycle (‰)	se of cycle (‰)
	nm Al2O3 Al2	nm Al2O3 Al2	nm Al2O3 Al2	nm Al2O3 Al2			
1	9.02219E-11	8.73334E-11	8.45213E-11	8.70968E-11	8.72934E-11	26.70	26.08
2	8.51120E-11	8.39871E-11	8.73837E-11	8.49542E-11	8.53593E-11	16.85	26.02
3	8.62433E-11	8.69654E-11	8.56177E-11	8.44285E-11	8.58137E-11	12.53	25.68
4	8.55459E-11	8.65106E-11	9.09629E-11	8.67023E-11	8.74304E-11	27.55	25.20
5	8.53798E-11	8.81419E-11	8.39445E-11	8.53801E-11	8.57116E-11	20.49	25.27
6	8.75635E-11	8.55912E-11	8.64610E-11	8.76866E-11	8.68256E-11	11.41	24.92
7	8.30340E-11	8.82101E-11	8.39491E-11	8.70678E-11	8.55653E-11	28.84	25.09
8	8.64026E-11	8.42623E-11	8.71233E-11	8.77584E-11	8.63867E-11	17.60	24.88
9	8.61990E-11	8.42064E-11	8.56231E-11	8.40342E-11	8.50157E-11	12.50	24.84
10	8.53038E-11	8.58034E-11	8.67534E-11	8.40966E-11	8.54893E-11	12.94	24.71
mean of sample	8.61006E-11	8.61012E-11	8.62340E-11	8.59206E-11	8.60891E-11		
relative sd of sample (‰)	21.59	18.50	24.12	17.41		relative sd (‰)	se (‰)
se of sample (‰)	25.68	25.34	24.56	25.48			
					all measurements	19.82	25.26
					over samples	1.49	7.99
					over cycles	9.81	12.63

= precision PASSED

correction factor 1.086

BACKGROUND SAMPLE

measured ratio	Al26/Al27
stated value	5E-14
required value	5E-14
counts/time	1 hour
sample name/position	Pos #40
measured value	3.60846E-14
corrected value	3.91909E-14

= background PASSED

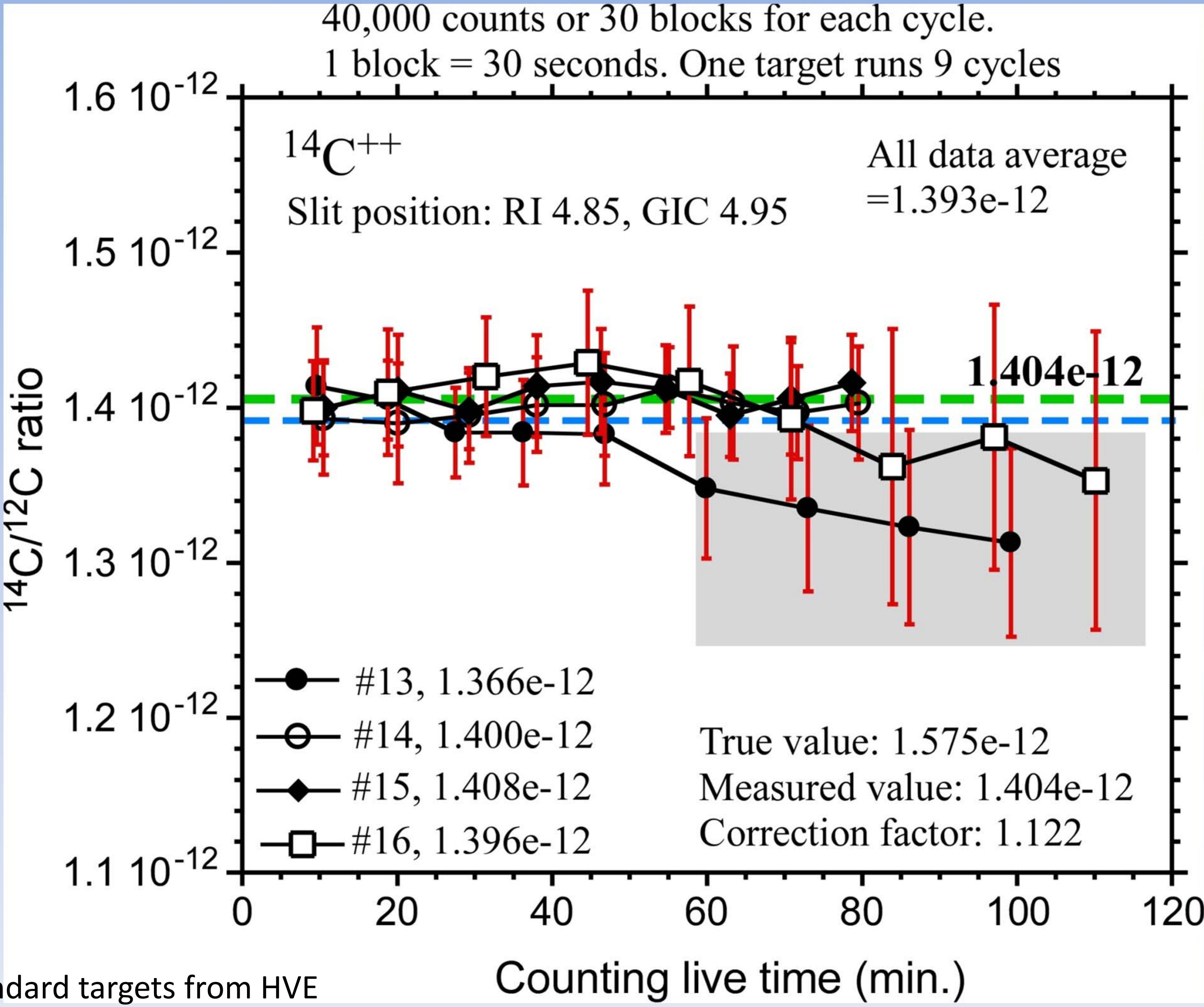
Check the following:

Measured ratios should not deviate too much from the stated value (in case no foils are used). Note: correction factor must be > 1.

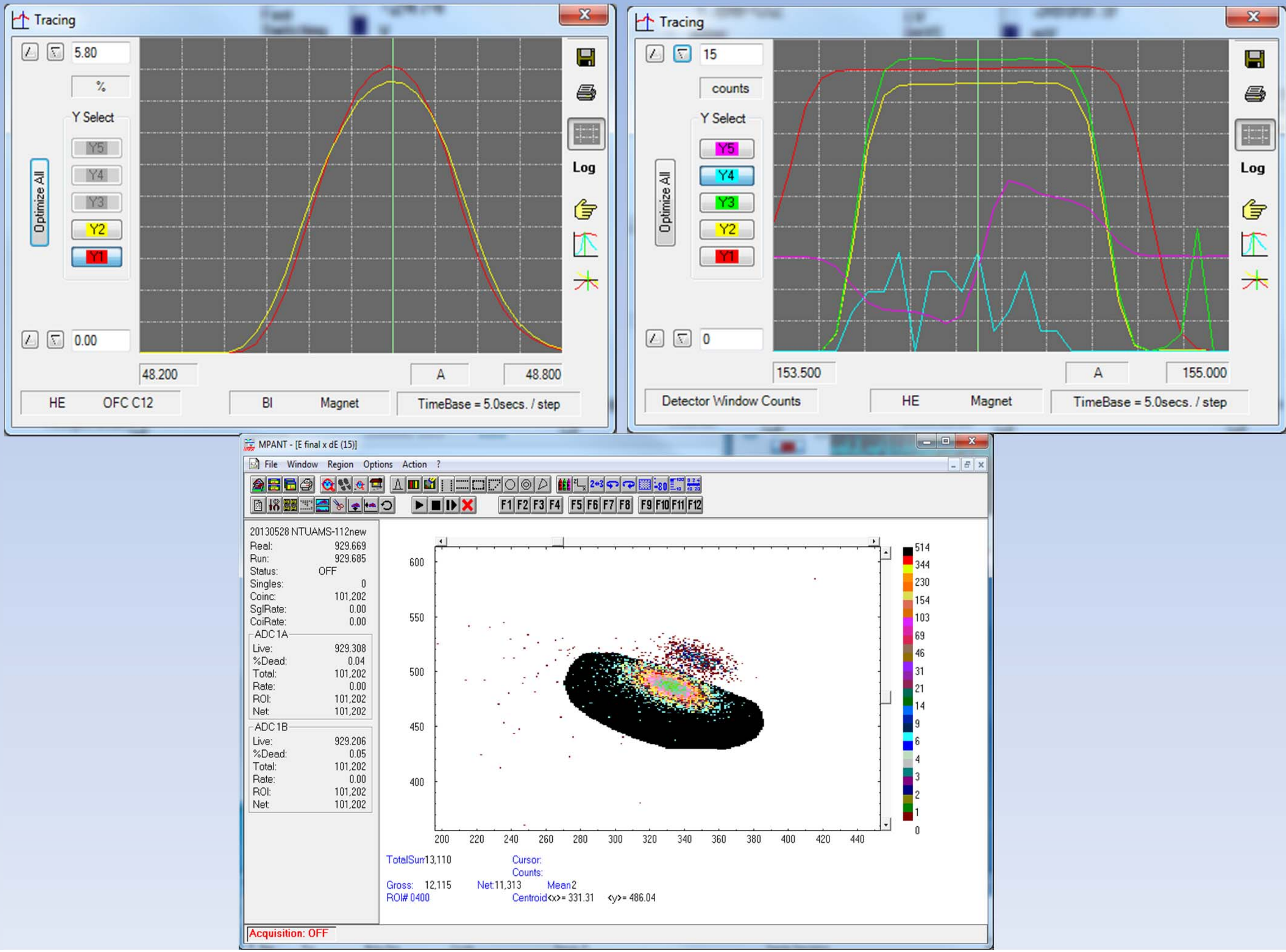
Relative standard deviation (sd) values should be around their corresponding mean statistical error (se) values.

The trend in the values of the column 'mean of cycle' is -1.43 ‰/cycle. Is current correction necessary?

No sample deviates more than 3 standard deviations from the mean of the other 3 samples.



Standard targets from HVE



Tracing
5.80
%
Y Select
Y5
Y4
Y3
Y2
Y1
Optimize All
0.00
48.200
A
48.800
Log
HE
OFC C12
BI
Magnet
TimeBase = 5.0secs. / step
Tracing
15
counts
Y Select
Y5
Y4
Y3
Y2
Y1
Optimize All
0
153.500
A
155.000
Log
Detector Window Counts
HE
Magnet
TimeBase = 5.0secs. / step
MPANT - [E final x dE (15)]
File Window Region Options Action ?
F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12
20130528 NTUAMS-112new
Real: 929.669
Run: 929.685
Status: OFF
Singles: 0
Coinc: 101,202
SglRate: 0.00
CoiRate: 0.00
ADC 1A
Live: 929.308
%Dead: 0.04
Total: 101,202
Rate: 0.00
ROI: 101,202
Net: 101,202
ADC 1B
Live: 929.206
%Dead: 0.05
Total: 101,202
Rate: 0.00
ROI: 101,202
Net: 101,202
600
550
500
450
400
200 220 240 260 280 300 320 340 360 380 400 420 440
514 344 230 154 103 69 46 31 21 14 9 6 4 3 2 1 0
TotalSum 13,110
Cursor:
Counts:
Gross: 12,115
Net: 11,313
Mean2
ROI# 0400
Centroid <x>= 331.31 <y>= 486.04
Acquisition: OFF

測量結果

FSI Batch

Batch Result

Used path: C:\ams-70\fsi-batch\20130528 C++ sample run\20130528 C++ sample run.fbres

No	Id	Description	C14 cnt	C13 cur	C12 cur	C14/C13	C14/C12	C13/C12
1	OX II 3		10031	1.64383e-008	1.28968e-006	5.68999e-011	7.25247e-013	1.27460e-002
2	NTUAMS-112 new	ANU	10289	5.78928e-008	4.72825e-006	7.00496e-011	8.57690e-013	1.22440e-002
3	NTUAMS-116	NTUB	44	1.40170e-008	1.07646e-006	1.91724e-013	2.49653e-015	1.30215e-002
4	NTUAMS-151	Shell	15049	6.21299e-008	5.29872e-006	5.47949e-011	6.42494e-013	1.17254e-002
5	NTUAMS-152	Shell	15199	4.89696e-008	4.09774e-006	6.31892e-011	7.55135e-013	1.19504e-002
6	NTUAMS-153	Shell	15175	5.79839e-008	4.89783e-006	5.71305e-011	6.76349e-013	1.18387e-002
7	NTUAMS-154	Shell	15201	5.38820e-008	4.41988e-006	6.26602e-011	7.63879e-013	1.21908e-002
8	NTUAMS-155	Shell	15115	6.19783e-008	5.25097e-006	5.72984e-011	6.76306e-013	1.18032e-002
9	NTUAMS-156	Shell	15035	4.74742e-008	4.00704e-006	5.69182e-011	6.74349e-013	1.18477e-002
10	NTUAMS-157	Shell	15164	6.40545e-008	5.49201e-006	5.16419e-011	6.02311e-013	1.16632e-002
11	NTUAMS-158	Shell	623	3.48515e-008	3.08560e-006	1.09291e-012	1.23443e-014	1.12949e-002
12	NTUAMS-168	Shell	345	6.31972e-008	5.46930e-006	3.33430e-013	3.85275e-015	1.15549e-002
13	NTUAMS-86		412	2.19384e-009	1.83559e-007	1.14699e-011	1.37085e-013	1.19517e-002
14	NTUAMS-135		10081	5.64277e-008	4.82136e-006	4.45421e-011	5.21307e-013	1.17037e-002
15	NTUAMS-136		10064	1.70917e-008	1.44884e-006	3.84680e-011	4.53800e-013	1.17968e-002
16	NTUAMS-139		10186	3.57964e-008	3.10789e-006	5.99450e-011	6.90441e-013	1.15179e-002
17	Carbon 3 mm pilot ...		0	2.21513e-010	1.52012e-008	0.00000e+000	0.00000e+000	1.45721e-002

AMS在测量未知样品的同时，还要测量已知的标准样品和本底样品

标准样品：是已知样品，消除AMS系统的传输效率不同和变化的影响（OX-1, OX-2，ANU）

本底样品：不含被测放射性核素粒子的样品，校正AMS系统的测量本底（自製）

被测样品：AMS要测多个未知样品提高年分析量（Throughout）

Graphitization line (6 units)

$$TOC\ (5\sim10\ mg) \xrightarrow[850^{o}C]{CuO\ (35\ mg)} CO_2 + others$$

$$CaCO_3\ (\sim10mg) + H_3PO_4\ (1ml) \longrightarrow CO_2 + others$$

CO_2 purification

1 mg C is needed

$$CO_2 + Zn \xrightarrow{425^{o}C} CO + ZnO$$

$$CO + Fe \xrightarrow{550^{o}C} C + FeO$$

Fe:C is 3:1

Graphite is pressed to target for measurement

※有機碳純化(右方示意圖①②區)

(5~10 mg 樣品+ 30~50 mg CuO + 銀片)放入石英管

↓

抽真空，以1400 ℃的火焰封管

↓

置入馬弗爐中進行＞5 小時850 ℃的灼燒反應

↓

將灼燒產生的CO_2純化後封於玻璃管內

※無機碳純化(右方示意圖②③區)

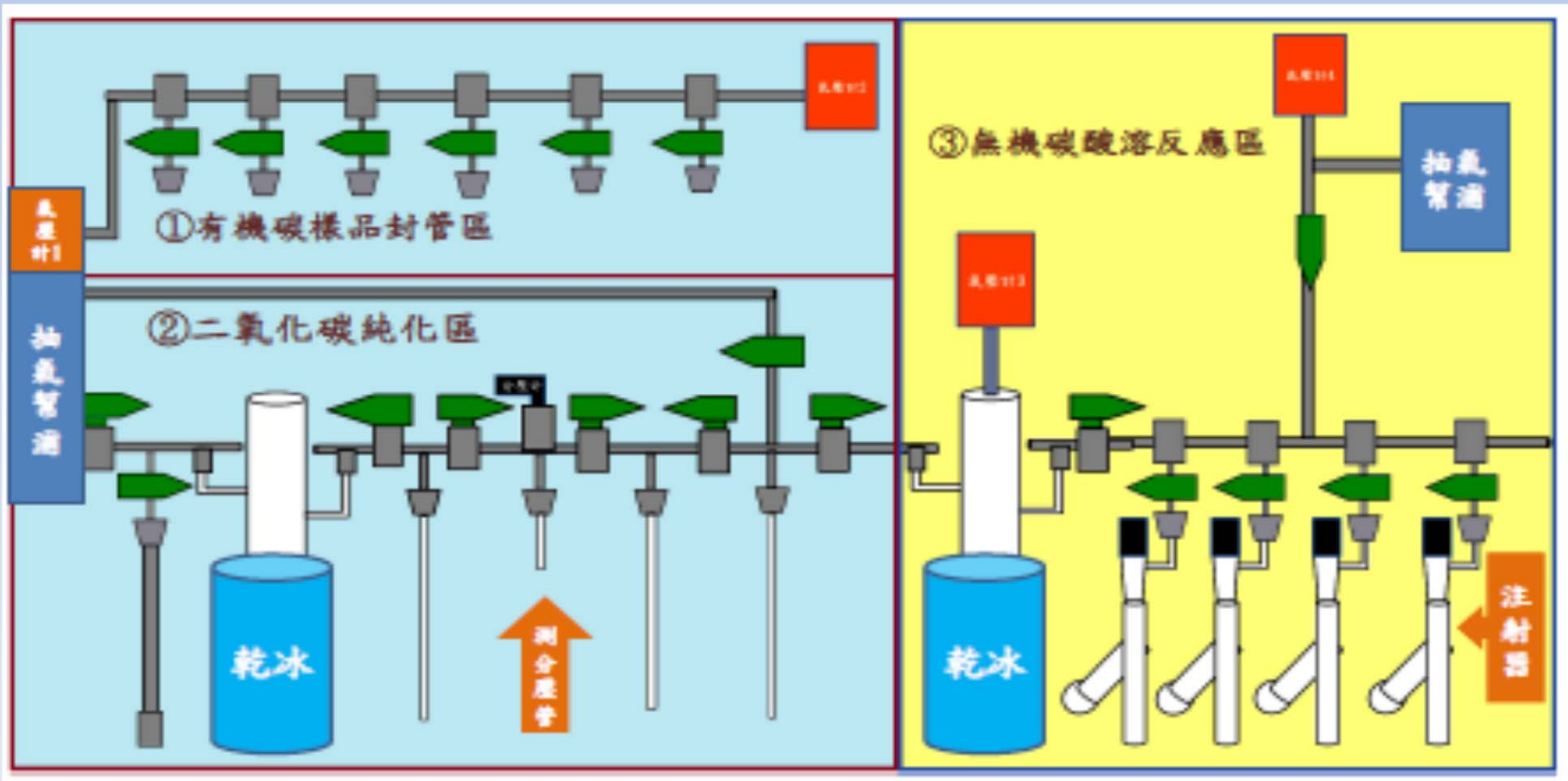
在注射器底部放置取 5~10 mg 的樣品、側壁放置1 mL 無水磷酸

↓

抽真空，使磷酸與樣品混合開始反應

↓

將酸溶產生的CO_2純化後封於玻璃管內



先利用 $C\,(mg) = 0.077234 + 0.0024507 \times P_{CO_2}$
此公式算出樣品中大約的含碳量。

取約 3.5 ~ 4 倍碳量的 Fe 粉、70~100 mg Zn 粉分別置入石英管中

↓

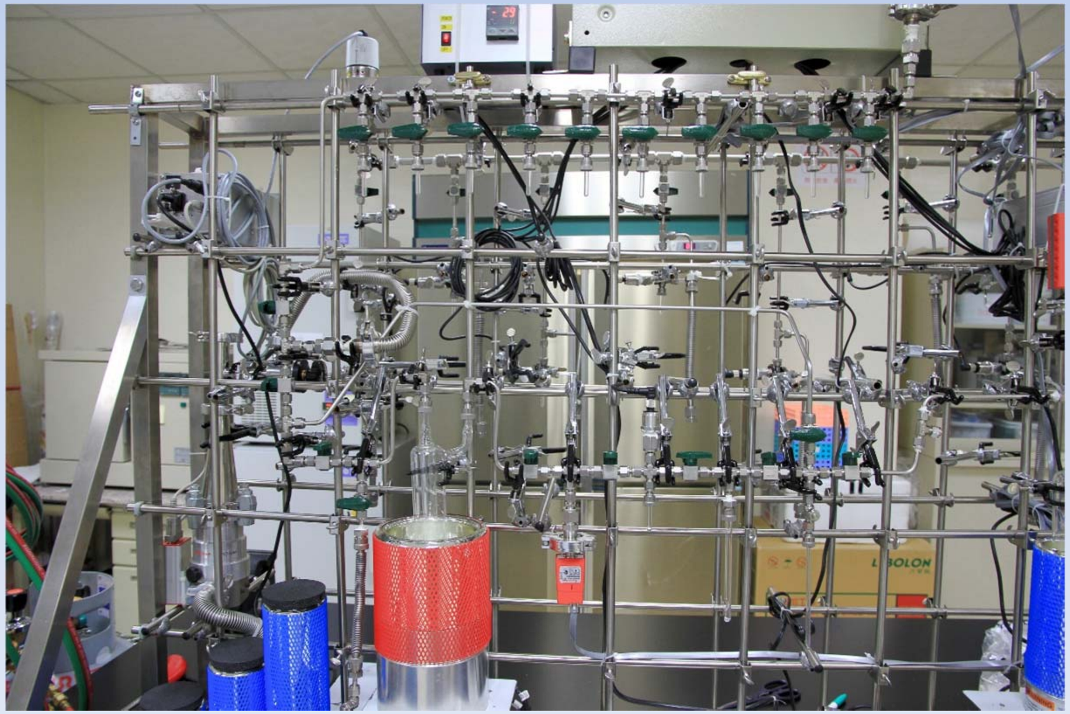
抽真空且預熱約1個小時

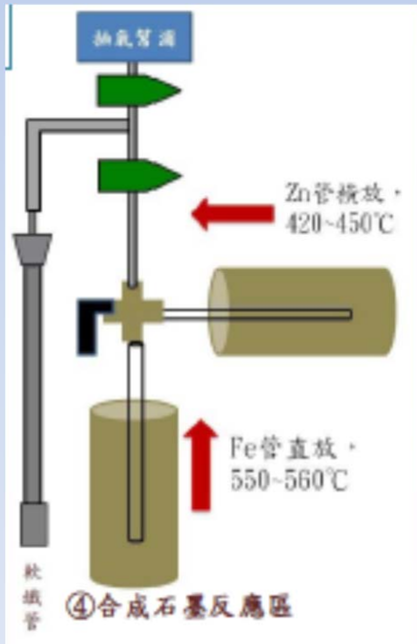
↓

待純化的CO_2氣體進入管柱後，開始合成反應

↓

石墨，製備靶材





Li_2^{++} interference problem

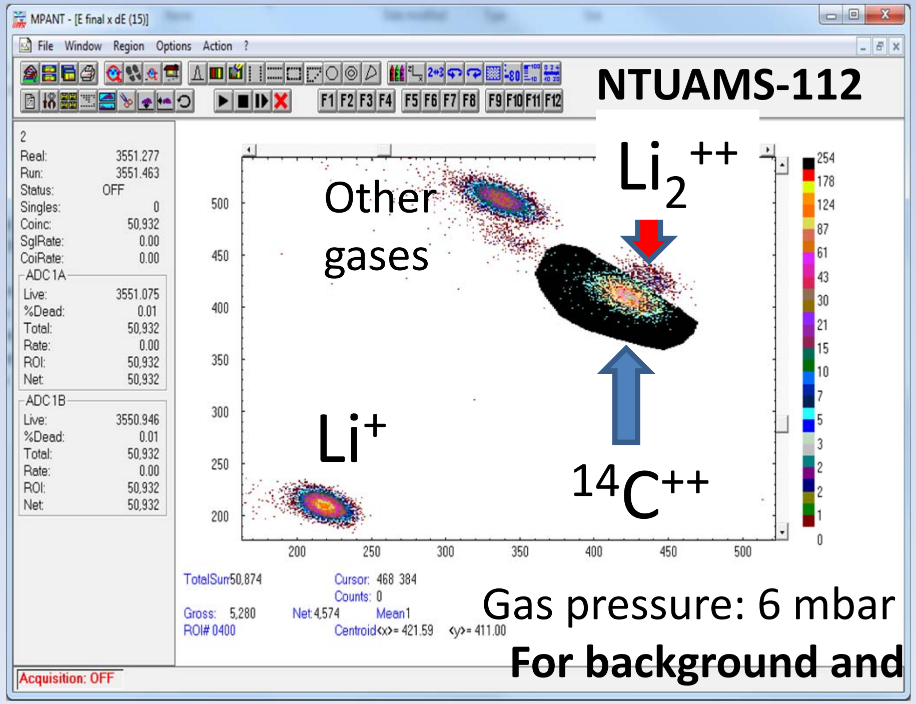
Lithium comes from quartz tube during graphite reaction.

Li_2^{++} has the same charge and close mass as $^{14}C^{++}$.

$^{14}C^{++}$ measurement

Slit positions: Rl out=4.85

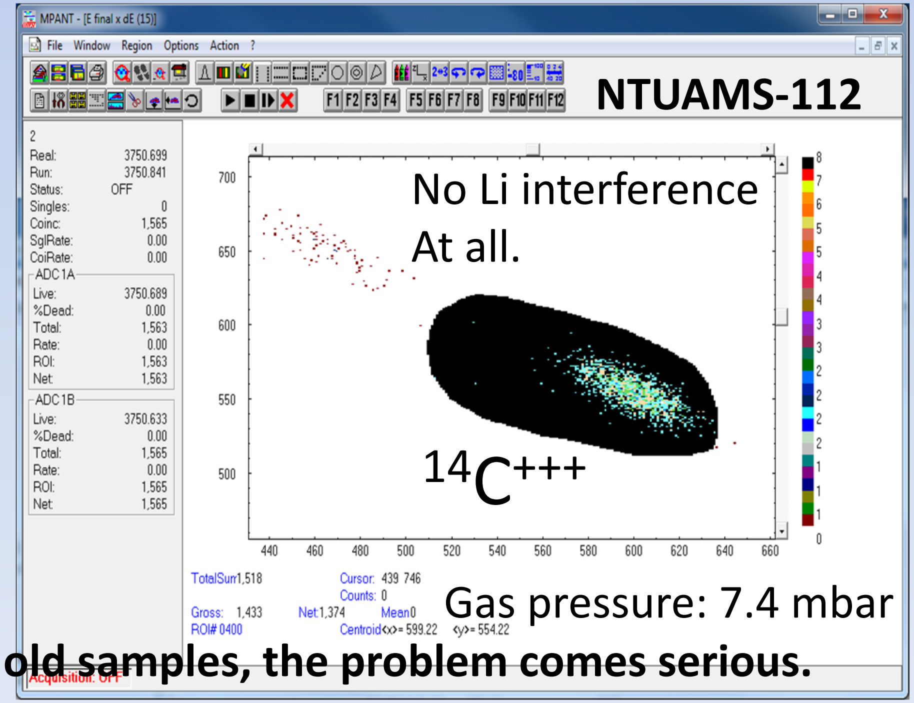
GIC out=4.95, in=5.1



$^{14}C^{+++}$ measurement

All slits are open

Transmission rate is 15%.



For background and old samples, the problem comes serious.

Meas. date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio	C+	RI out Slit	GIC out slit	Li interf.
March 6, 2013	3.79E-07	5548	1.34	1.49E-12	1.06E-02	C^{++}	4.85	4.95	ok
March 6, 2013	2.18E-07	1433	2.64	1.00E-12	8.77E-03	C^{+++}	open	open	no
April 1, 2013	1.26E-06	9942	1.00	1.21E-12	9.08E-03	C^{+++}	open	open	no
April 1, 2013	3.32E-06	10298	0.99	1.23E-12	9.06E-03	C^{+++}	open	open	no
May 26, 2013	6.21E-06	20289	0.70	1.29E-12	1.18E-02	C^{++}	4	7	yes
May 26, 2013	8.29E-06	20199	0.70	1.03E-12	1.16E-02	C^{++}	3	7	no
May 28, 2013	4.73E-06	10289	0.99	8.58E-13	1.22E-02	C^{++}	3	7	no

$^{14}C^{++}$ meas.

Slit positions:

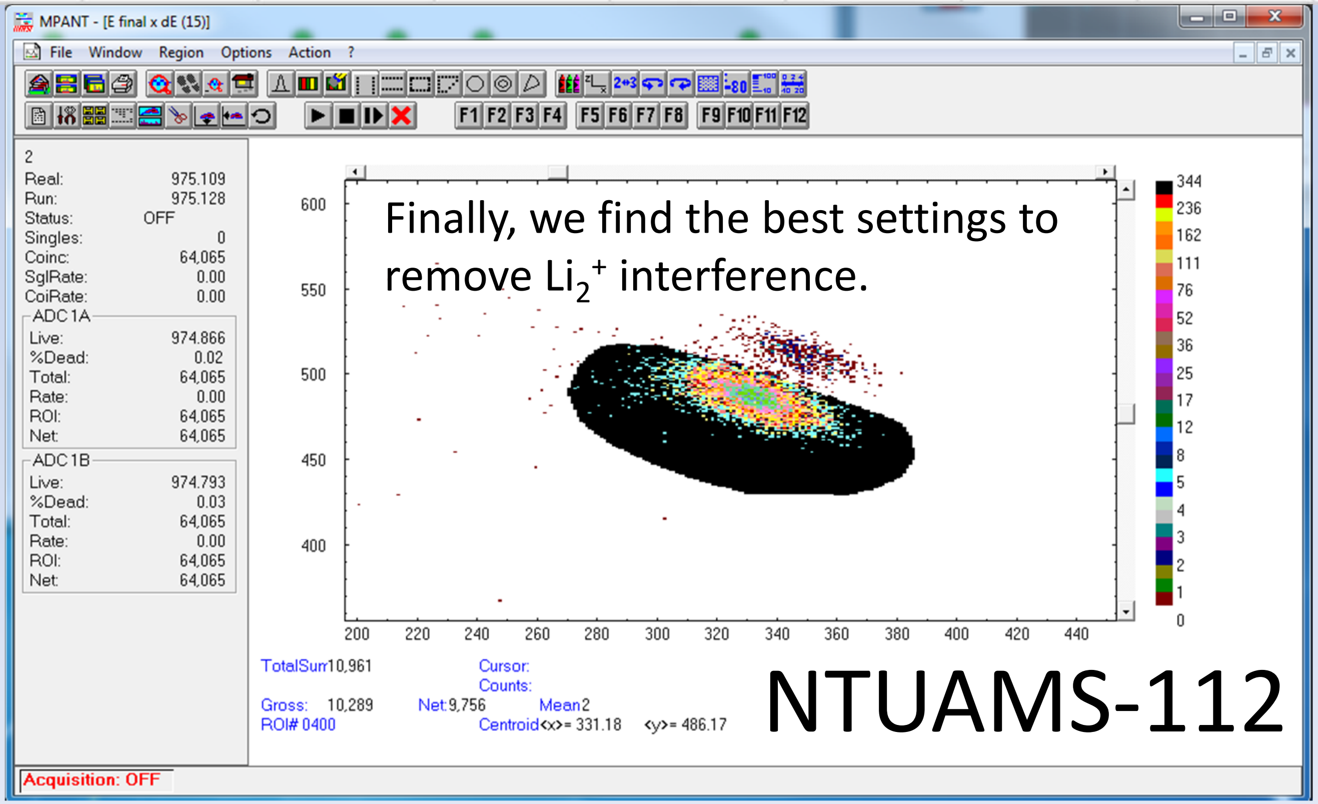
RI out=3.0

RI in=open

GIC out=7.0

GIC in=7.0

Gas pressure:7.5



國際標準品的測量$^{14}C^{+++}$

ANU

Lab code	Meas, date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio
NTUAMS-13	2,01,13	7.88E-07	4163	1.55	8.062E-13	9.285E-03
NTUAMS-14	2,01,13	1.85E-06	10360	0.98	8.552E-13	9.260E-03
NTUAMS-62	4,23,13	4.85E-06	10098	1.00	8.471E-13	9.061E-03
NTUAMS-107	3,06,13	1.41E-07	553	4.25	5.981E-13	8.465E-03
					8.361E-13	9.202E-03
					2.627E-14	1.230E-04

OX-1

Lab code	Meas, date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio
NTUAMS-68	4,24,13	2.76E-08	283	5.94	9.406E-13	1.057E-02
NTUAMS-111	3,06,13	2.25E-07	1494	2.59	1.015E-12	8.822E-03
NTUAMS-112	4,01,13	1.26E-06	9942	1.00	1.209E-12	9.083E-03
NTUAMS-112	3,06,13	2.18E-07	1433	2.64	1.003E-12	8.775E-03
NTUAMS-112	4,01,13	3.32E-06	10298	0.99	1.234E-12	9.061E-03
					1.221E-12	9.072E-03
					1.763E-14	1.551E-05

OX-2

Lab code	Sample ID	Meas, date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio
NTUAMS-65	OX-2	4,23,13	6.40E-07	6852	1.21	9.815E-13	8.892E-03
NTUAMS-66	OX-2	4,24,13	3.08E-06	10157	0.99	1.079E-12	8.986E-03

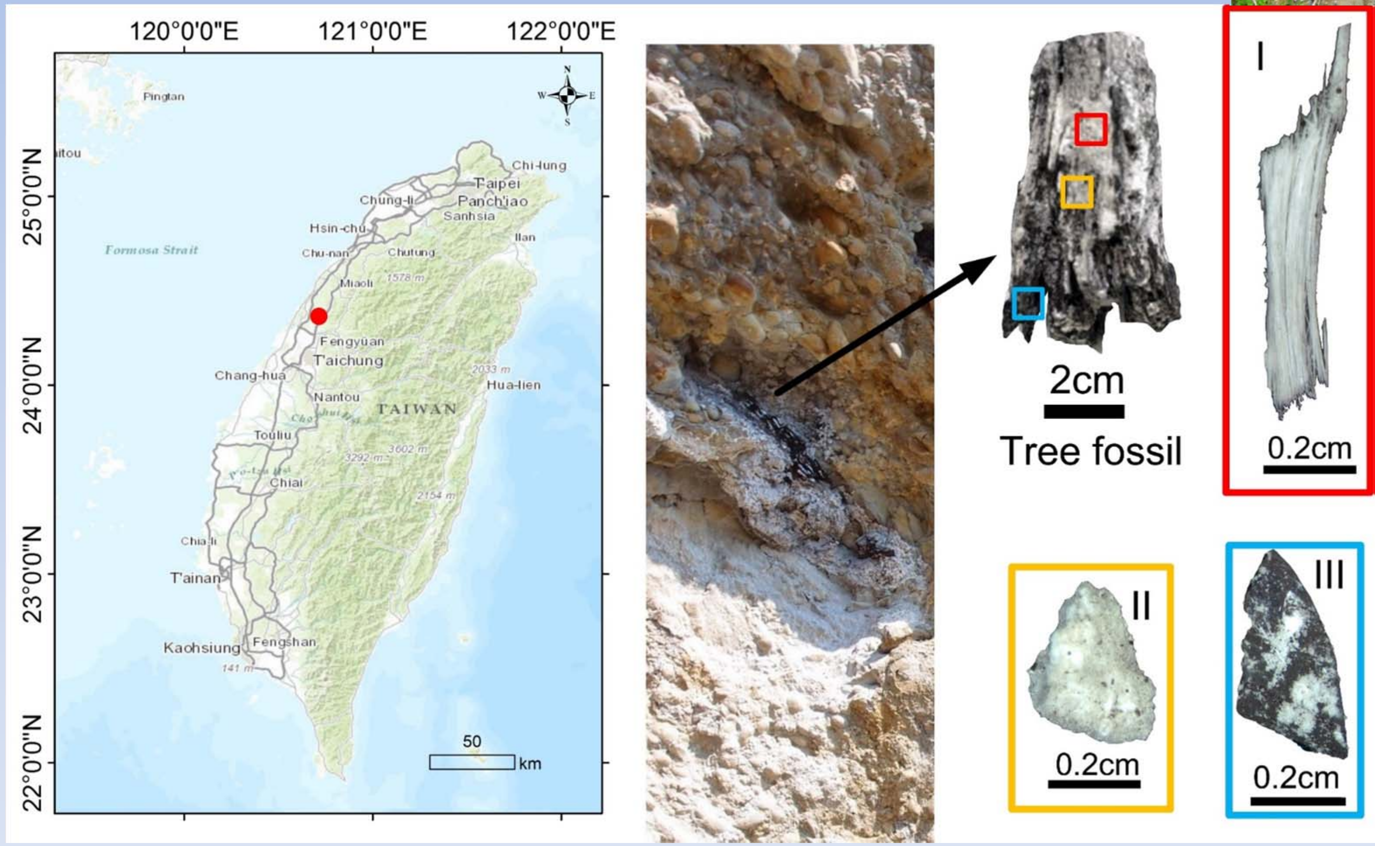
We have processed the principal modern radiocarbon standards including Oxalic Acid I (HOx1), Oxalic Acid II (HOx2) and ANU (Australian National University) sucrose.

	C+++ mode				C++ mode, Slit RI out=4.85, GIC out=4.95			
	$^{14}C/^{12}C$ ratio	Stdev	$^{13}C/^{12}C$ ratio	Stdev	$^{14}C/^{12}C$ ratio	Stdev	$^{13}C/^{12}C$ ratio	Stdev
OXI	8.361E-13	2.627E-14	9.202E-03	1.230E-04	1.080E-12	1.495E-14	1.062E-02	1.152E-04
OXII	1.079E-12	7.110E-14	8.986E-03	3.043E-05	1.460E-12	7.073E-13	1.072E-02	2.250E-04
ANU	1.221E-12	1.763E-14	9.072E-03	1.551E-05	1.562E-12	5.946E-14	1.075E-02	1.718E-04
OXII/OXI	1.2905E+00				1.351E+00			
ANU/OXI	1.4607E+00				1.446E+00			

The activity ratio of HOx2/HOx1 for our measurements is 1.2905, similar to the reported ratio of 1.2933±0.001. However, the activity ratio of ANU/HOx1 for our measurements is 1.4606 which is slightly lower than the reported ratio of 1.5081.

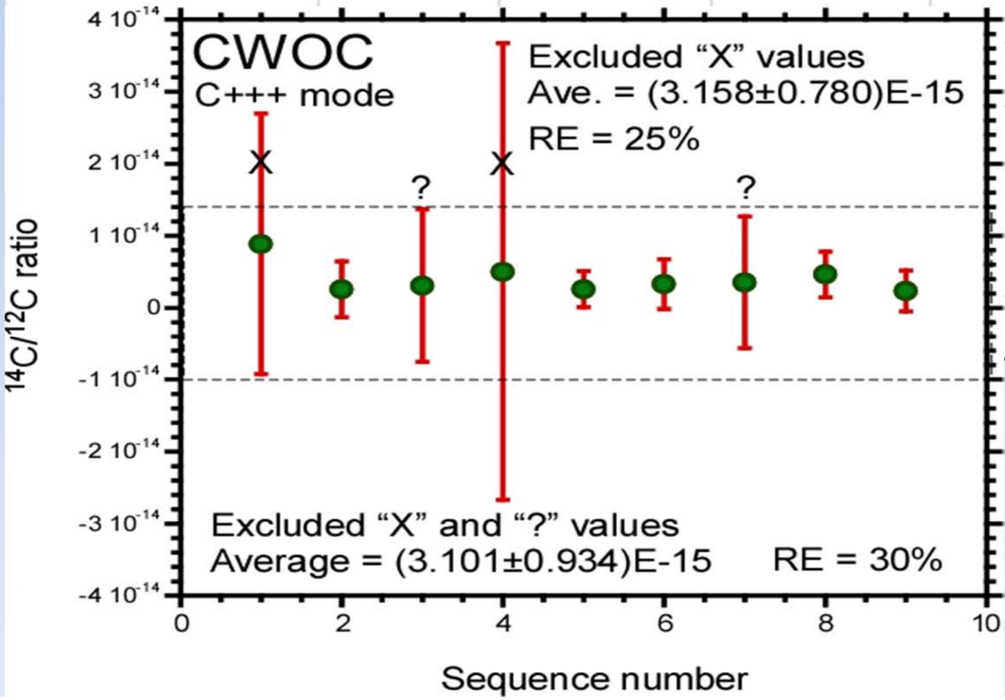
本底樣品的選擇與測試

苗栗火炎山香山相層埋藏炭化木



炭化木樣品可分為三部分：(I)纖維狀結晶礦物，(II)灰白色鬆散膠結物，(III)黑色炭化木。 (II)有一些雜質、炭化木碎屑混雜其中；(III)表面也有(I)和(II)未刮除。

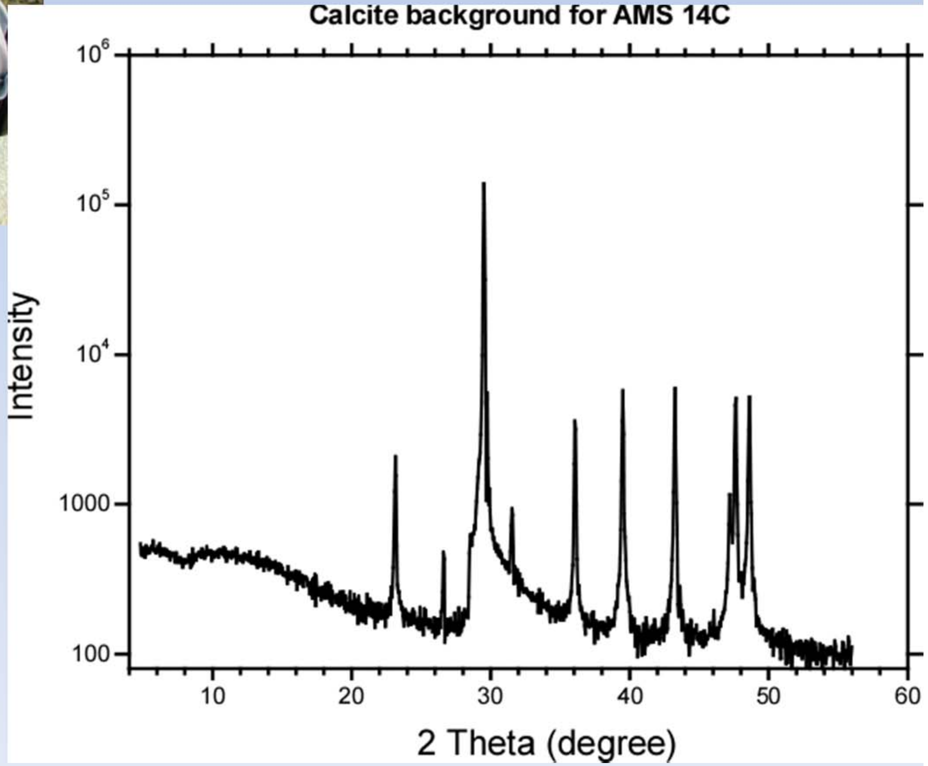
Lab code	C (mg)	Meas. date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio
NTUAMS-120	0.81	4,24,13	4.66E-07	45	14.91	8.848E-15	8.296E-03
NTUAMS-141	1.11	4,23,13	3.89E-06	110	9.54	2.592E-15	9.084E-03
NTUAMS-142	1.65	4,23,13	4.46E-07	15	25.82	3.081E-15	8.975E-03
NTUAMS-144	2.42	4,23,13	5.49E-08	3	57.74	5.008E-15	8.837E-03
NTUAMS-145	1.75	5,08,13	5.78E-06	164	7.81	2.601E-15	8.965E-03
NTUAMS-146	1.00	5,08,13	4.97E-06	179	7.47	3.300E-15	8.954E-03
NTUAMS-148	0.55	5,08,13	1.35E-06	52	13.87	3.521E-15	9.046E-03
NTUAMS-149	1.30	5,08,13	8.21E-06	417	4.90	4.650E-15	8.974E-03
NTUAMS-150	0.76	5,08,13	6.71E-06	173	7.60	2.363E-15	9.006E-03
					Average	3.996E-15	8.904E-03
					Stdev	2.035E-15	2.379E-04
					Average	3.158E-15	9.001E-03
					Stdev	7.797E-16	4.819E-05
					Average	3.101E-15	8.997E-03
					Stdev	9.346E-16	5.269E-05



$^{13}C/^{12}C = 0.0089$

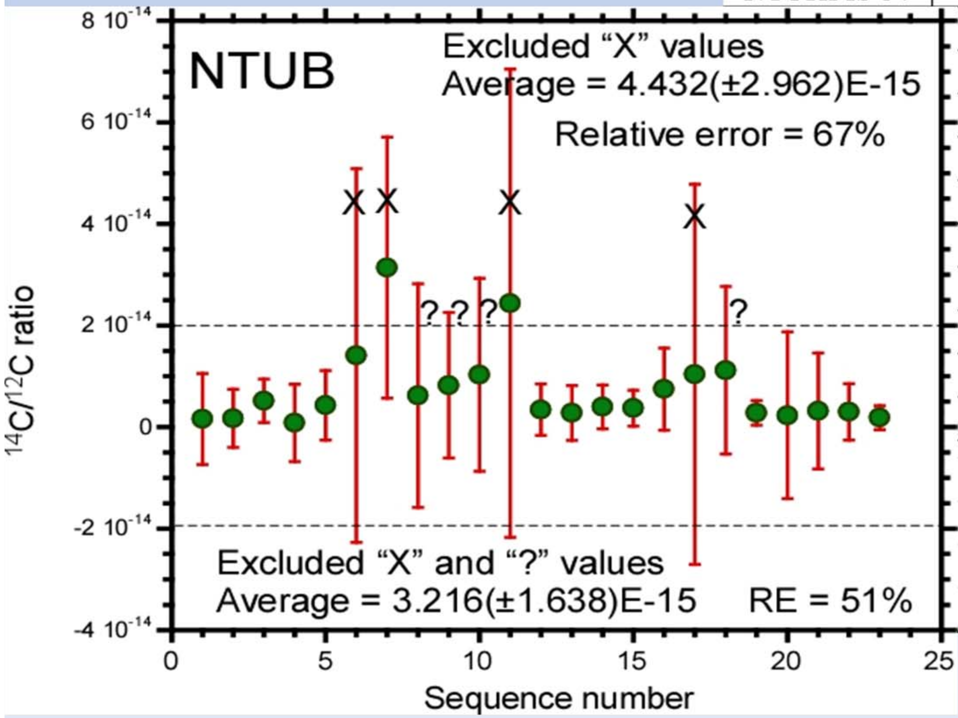
桂林丫吉村上泥盆統石灰岩方解石，NTUB

Ca, Mg, Na, K, Sr, Mn and Li are 395735, 1189, 1121, 75.6, 23.6, 20.3 and 4.2 (mg/Kg), respectively. Ba, Cu, Zn, Ni, Pb, Co and Cr are below detection limit.



The $^{14}C/^{12}C$ ratios of NTUB and CWOC are very close to the AMS background of 2.748E-15.

Lab code	C (mg)	Meas, date	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{13}C / ^{12}C Ratio
NTUAMS-29	3.52	2,01,13	5.69E-07	6	40.83	1.609E-15	1.030E-02
NTUAMS-30b	1.86	2,05,13	1.13E-06	16	25.00	1.737E-15	1.079E-02
NTUAMS-30c	2.81	4,23,13	6.98E-06	394	5.04	5.171E-15	9.168E-03
NTUAMS-30c	2.81	2,05,13	4.42E-07	3	57.74	8.288E-16	9.785E-03
NTUAMS-31a	2.30	2,01,13	1.92E-06	54	13.61	4.301E-15	9.729E-03
NTUAMS-31c	1.54	2,06,13	2.27E-07	21	21.82	1.412E-14	9.106E-03
NTUAMS-31c	1.54	2,02,13	1.17E-06	240	6.46	3.144E-14	9.332E-03
NTUAMS-31d	1.04	2,02,13	2.46E-07	10	31.62	6.197E-15	9.830E-03
NTUAMS-31e	2.00	2,06,13	7.40E-07	40	15.81	8.257E-15	1.011E-02
NTUAMS-31e	2.00	2,02,13	9.49E-07	64	12.50	1.029E-14	9.464E-03
NTUAMS-31f	1.23	2,02,13	1.87E-07	30	18.26	2.444E-14	9.352E-03
NTUAMS-34	1.86	2,06,13	2.85E-06	64	12.50	3.431E-15	1.177E-02
NTUAMS-34	1.86	2,02,13	2.41E-06	44	15.08	2.791E-15	9.275E-03
	1.05	2,01,13	4.19E-06	109	9.58	3.971E-15	9.253E-03
	1.41	2,01,13	6.22E-06	152	8.11	3.729E-15	9.255E-03
	0.89	2,01,13	3.79E-06	186	7.33	7.485E-15	9.371E-03
	0.74	2,01,13	2.79E-07	19	22.94	1.040E-14	9.615E-03
	1.19	2,01,13	7.89E-07	58	13.13	1.122E-14	9.520E-03
	1.07	2,01,13	6.56E-06	121	9.09	2.815E-15	9.324E-03
	1.71	2,05,13	6.30E-07	12	28.87	2.327E-15	9.945E-03
	1.71	2,05,13	6.15E-07	16	25.00	3.176E-15	1.054E-02
	1.90	4,24,13	2.87E-06	94	10.31	3.006E-15	9.218E-03
	2.31	4,25,13	5.26E-06	107	9.67	1.864E-15	9.189E-03
					Average	4.432E-15	9.781E-03
					Stdev	2.962E-15	6.825E-04
					Average	3.216E-15	9.795E-03
					Stdev	1.638E-15	7.608E-04



$^{13}C/^{12}C = 0.0098$

Materials can be applied for ^{14}C dating

- ***Plant remains***: Charcoal, wood, twigs, seeds, pollen, peat
- ***Animal remains***: Bone, Hair, Blood residues, Coprolites, Antler and horn; Fish remains, Insect remains
- ***Carbonates (TIC)*** : Corals, foraminifera, tufa and speleothems; Marine, estuarine and riverine shell; Avian eggshell
- ***Sediments (TOC)*** : Soil, Lake muds (gyttja) and sediments
- ***Water***: Ice cores, groundwater
- ***Man-made stuffs***: Textiles and fabrics; Leather, Paper and parchment; Wall paintings and rock art works; Pottery; Resins and glues
- ***Others***: Metal casting ores; Iron and meteorites

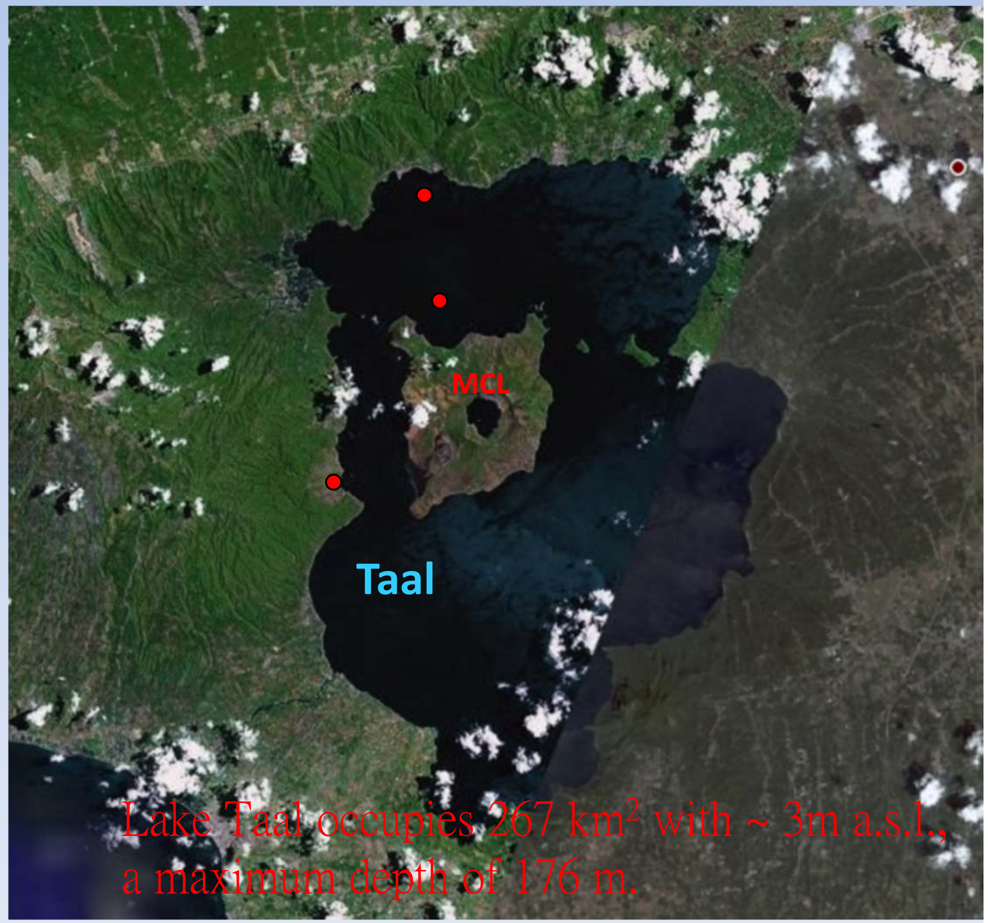
Applications

- ARCHAEOLOGY—Too many examples
- GLOBAL CHANGE—Carbon cycle and others
- OCEANOGRAPHY—Sealevel change, ocean circulation, coral dating, etc.
- PALAEOCLIMATOLOGY—Dating on geological archives (plant and animal remains in marine and terristrial sediments, organic and inorganic forms of geological materials)
- ENVIRONMENTAL STUDIES—e.g., Dating and tracing of groundwaters
- CALIBRATION AND DENDROCHRONOLOGY
- METEOROLOGY
- 醫學（示蹤）、法學（鑑定）

Taal Lake project

Taal Volcano (14˚00.1'N, 120˚ 59.1'E) is one of the 16 most active volcanoes in the world. 33 historic events were recorded.

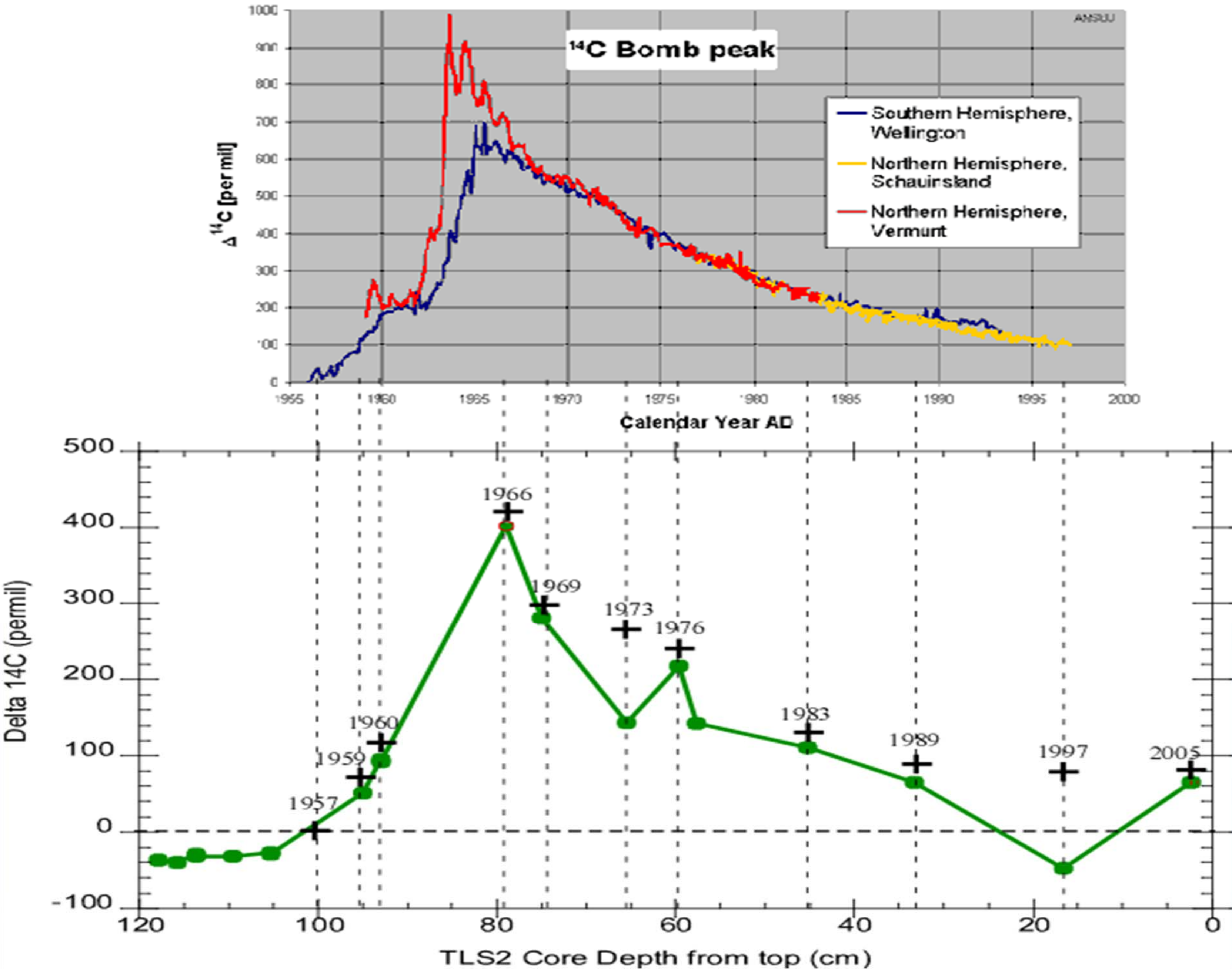
Taal Volcano system probably formed between 140,000 and 5,380 yrs BP. Taal Volcano Island which has 47 craters and 4 maars, lies in the N central Lake Taal.



Plant remains
Shells
TOC in carbonate-free sediments

AMS ^{14}C dating results on organic carbons in Core TLS2

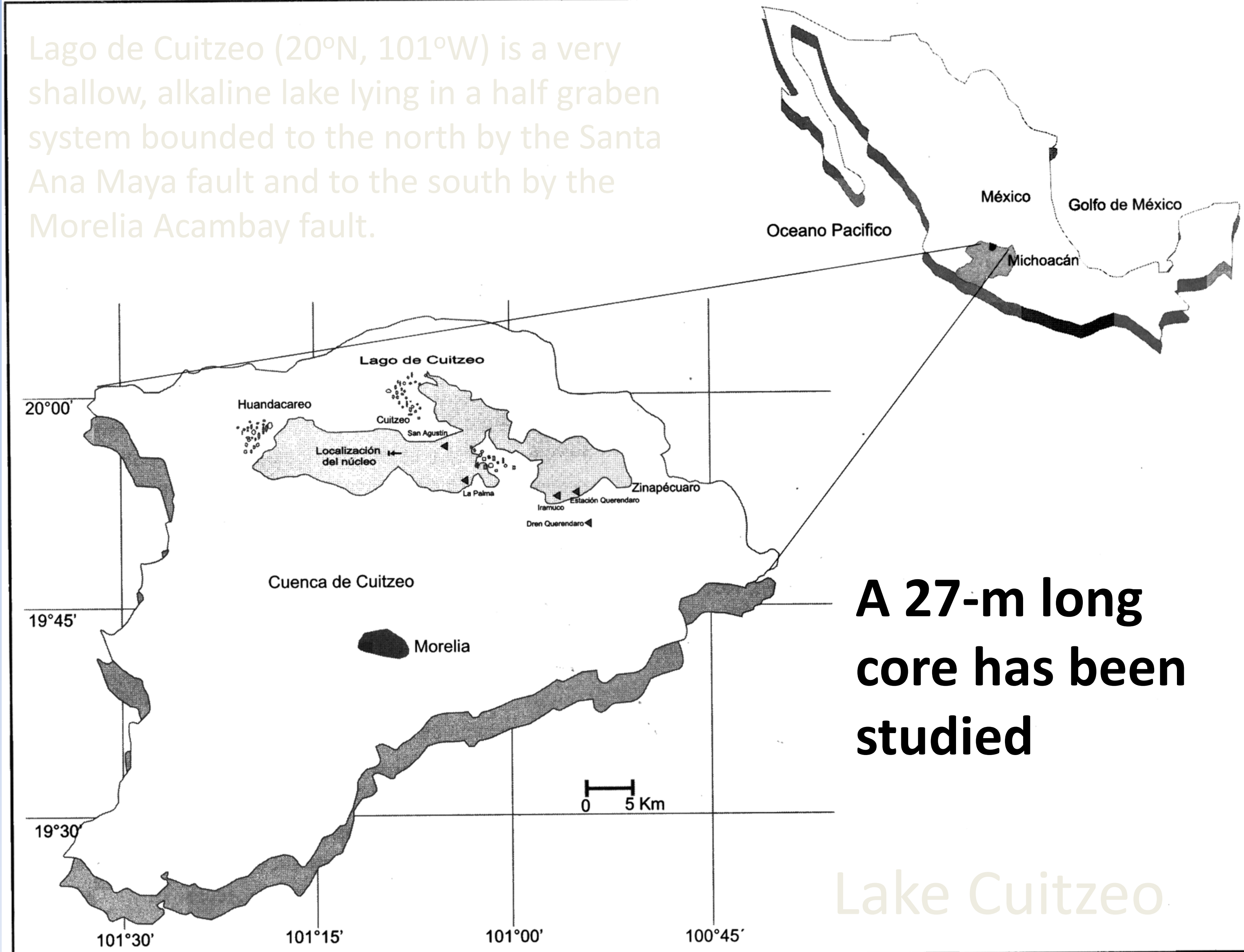
Sample ID	UCIAMS	Sample name	$\delta^{13}C$ (‰)	±	Fraction Modern	±	? ^{14}C (‰)	±	^{14}C age (BP)	±	Depth (cm)	Year* (AD)	Cal. Year** (AD)
TLS2-01	49021	UCIT17657	-24.2	0.15	1.0726	0.0014	65.1	1.4	-560	15	2.38	2005	2004
TLS2-07	49022	UCIT17658	-27.3	0.15	0.9586	0.0016	-48.1	1.6	340	15	16.66	1997	1997
TLS2-14	49023	UCIT17659	-16.2	0.15	1.0730	0.0015	65.5	1.5	-560	15	33.32	1989	1989
TLS2-19	48695	UCIT17627	-27.3	0.15	1.1184	0.0014	110.6	1.4	-895	15	45.22	1983	1983
TLS2-25	49352	UCIT17660			1.1507	0.0019	142.7	1.9	-1125	15	57.72	1977	1977
TLS2-26	48696	UCIT17628	-26.6	0.15	1.2267	0.0016	218.2	1.6	-1635	15	59.65	1976	1976
TLS2-29	49353	UCIT17661	-27.7	0.15	1.1519	0.0019	143.8	1.9	-1130	15	65.44	1973	1973
TLS2-34	49354	UCIT17662	-26.2	0.15	1.2906	0.0021	281.6	2.1	-2045	15	75.09	1969	1969
TLS2-36	49355	UCIT17663	-26.0	0.15	1.4118	0.0025	401.9	2.5	-2765	15	79.00	1966	1967
TLS2-43, NT	44272	UCIT17154	-29.7	0.15	1.0993	0.0024	91.6	2.4	-755	20	93.00	1960	1960
TLS2-43, ABA	47137	UCIT17406R	-30.1	0.15	1.1023	0.0016	94.6	1.6	-780	15	93.00	1960	1960
TLS2-44A	48697	UCIT17629	-27.9	0.15	1.0593	0.0014	51.9	1.4	-460	15	95.00	1959	1959
TLS2-49, NT	44273	UCIT17155	-27.1	0.15	0.9784	0.0021	-28.5	2.1	175	20	105.30		1954
TLS2-49, ABA	47138	UCIT17407	-27.8	0.15	0.9800	0.0012	-26.8	1.2	160	10	105.30		1954
TLS2-51, ABA	47139	UCIT17408	-29.4	0.15	0.9752	0.0014	-31.6	1.4	200	15	109.50		1952
TLS2-53, NT	44274	UCIT17156	-28.1	0.15	0.9749	0.0021	-31.9	2.1	205	20	113.70		1950
TLS2-53, ABA	47140	UCIT17409	-29.3	0.15	0.9782	0.0012	-28.7	1.2	175	10	113.70		1950
TLS2-54	49018	UCIT17630	-27.6	0.15	0.9665	0.0013	-40.3	1.3	275	15	115.80		1949
TLS2-55	49019	UCIT17631	-28.5	0.15	0.9701	0.0015	-36.7	1.5	245	15	117.90		1947
TLS1-A, ABA	47141	UCIT17410R	-31.3	0.15	0.9739	0.0013	-32.9	1.3	215	15	1.2		
TLS1-AG, ABA	47142	UCIT17411R	-26.5	0.15	1.0170	0.0013	9.9	1.3	-130	15	38.5		
TLS1-BM, ABA	47143	UCIT17412R	-25.5	0.15	0.8643	0.0012	-141.8	1.2	1170	15	72.0		



14C Bomb peak
ANSIJ
Southern Hemisphere, Wellington
Northern Hemisphere, Schauinsland
Northern Hemisphere, Vermunt
Δ 14C [per mil]
Calendar Year AD
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Delta 14C (permil)
TLS2 Core Depth from top (cm)
1957
1959
1960
1966
1969
1973
1976
1983
1989
1997
2005

Lake Cuitzeo Project

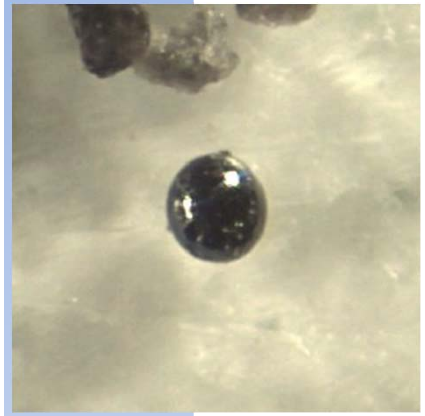
Lago de Cuitzeo (20ºN, 101ºW) is a very shallow, alkaline lake lying in a half graben system bounded to the north by the Santa Ana Maya fault and to the south by the Morelia Acambay fault.

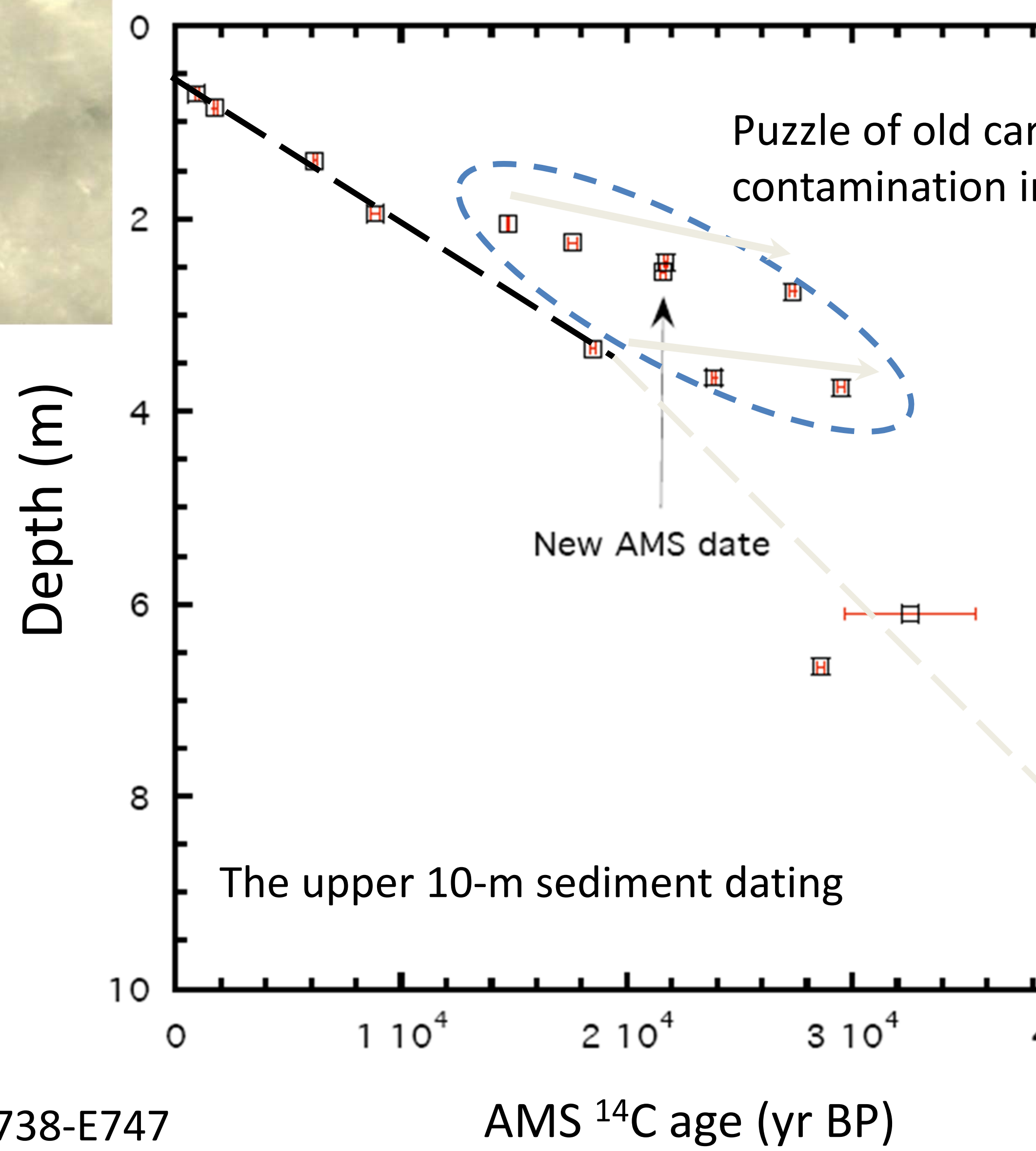


A 27-m long core has been studied

Lake Cuitzeo

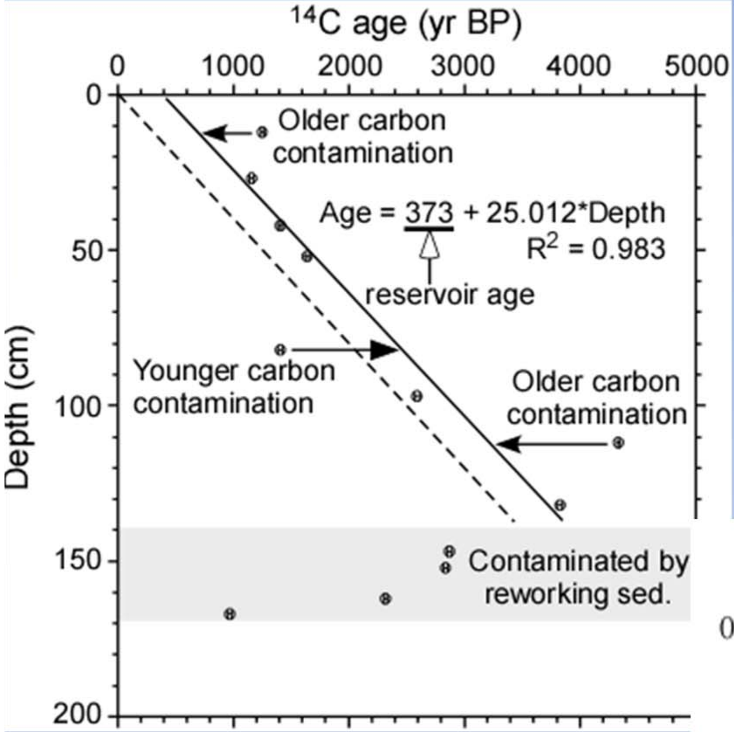
Allen West said: The sample at 2.80 m of the core has the highest concentration of spherules he has yet seen!





PNAS, 2012, E738-E747

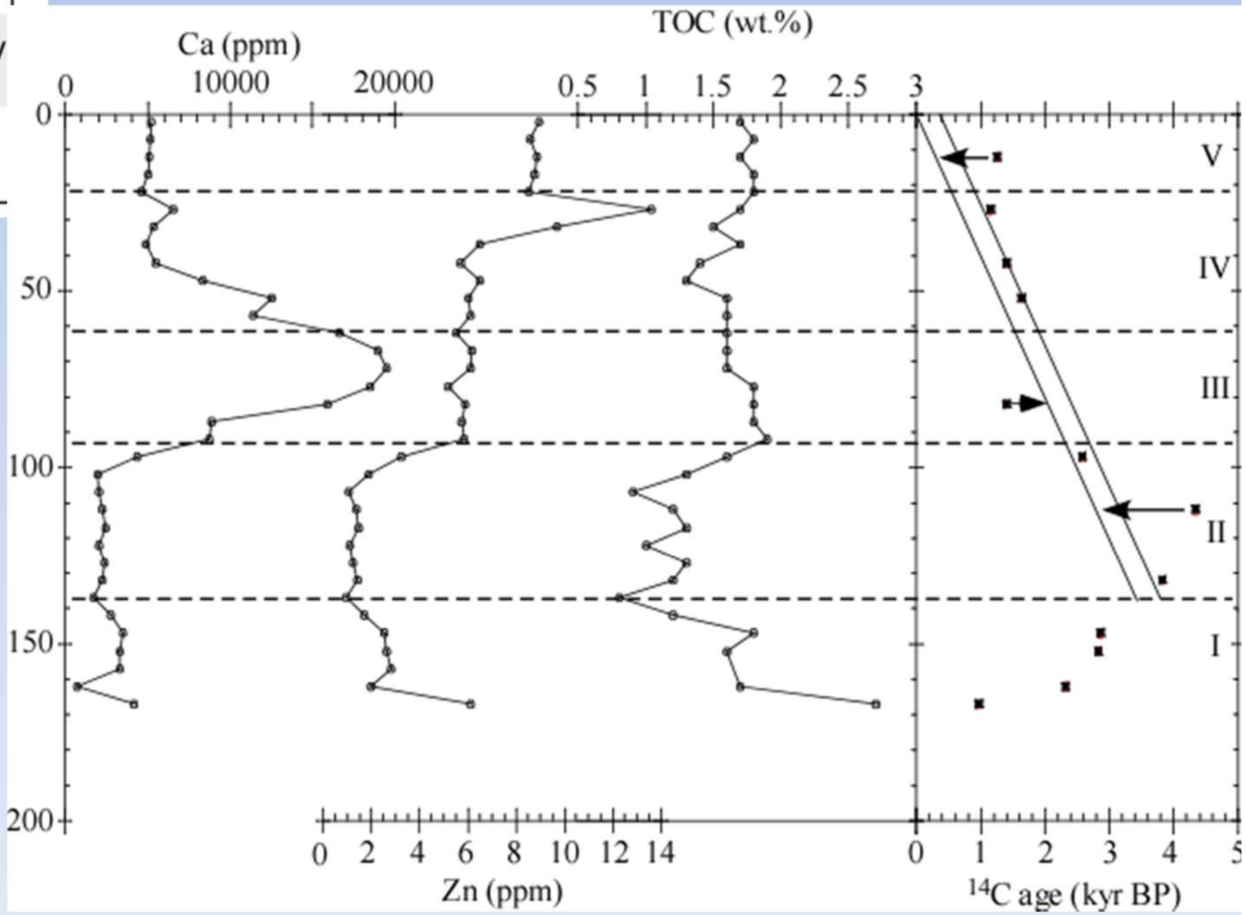
AMS C-14 dating on soil profile
Anshun, Guizhou

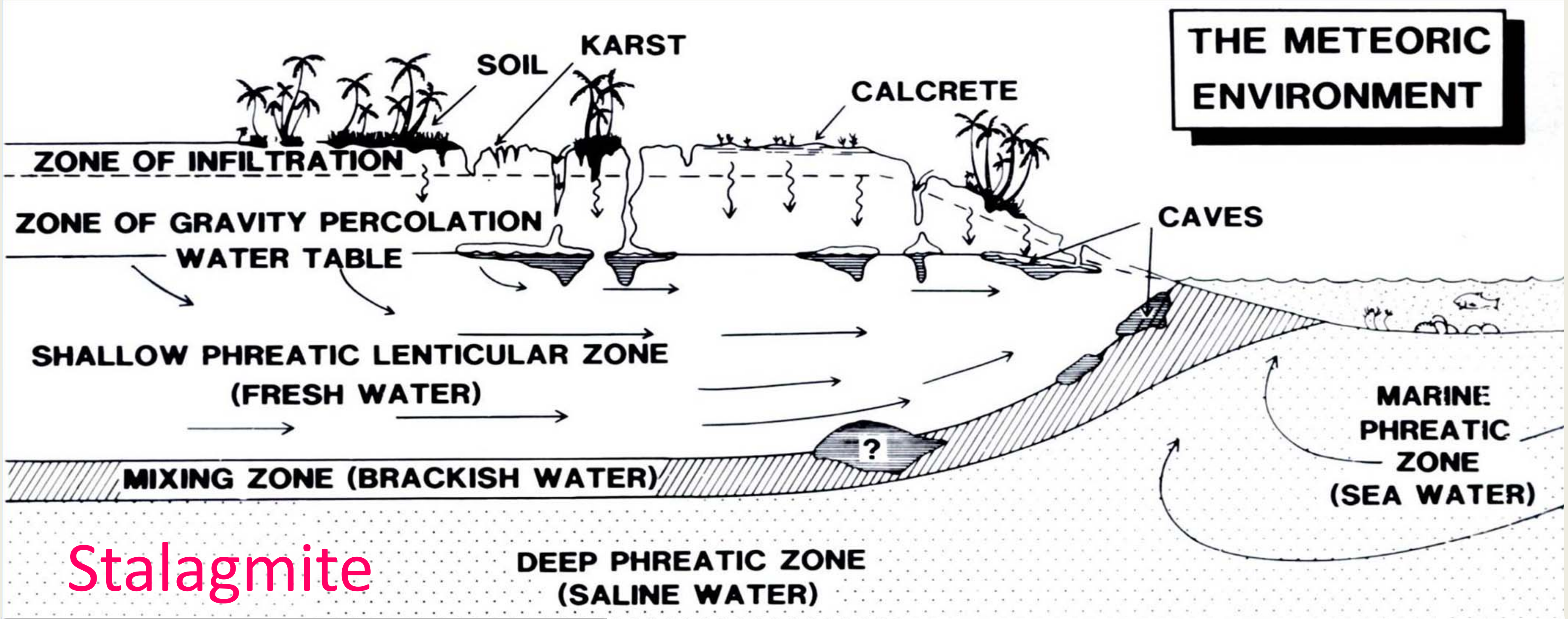


Reservoir age

Old carbon contamination

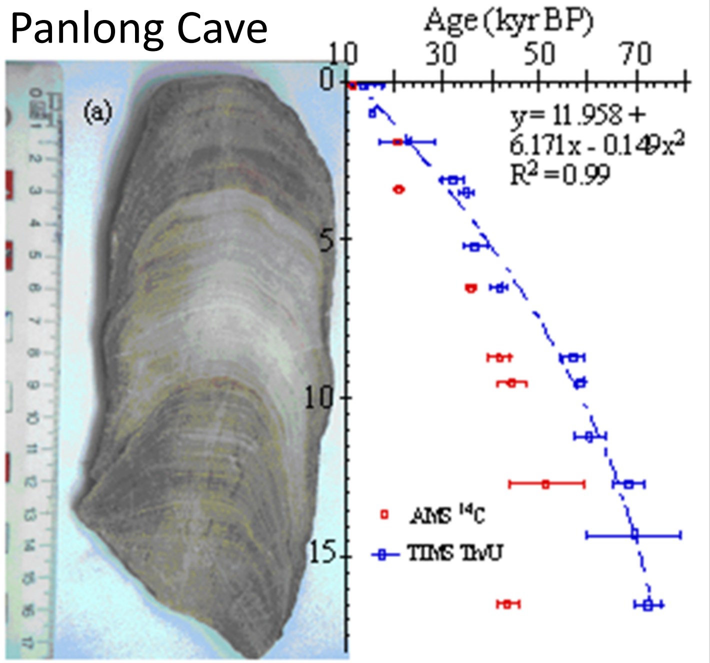
Young carbon contamination





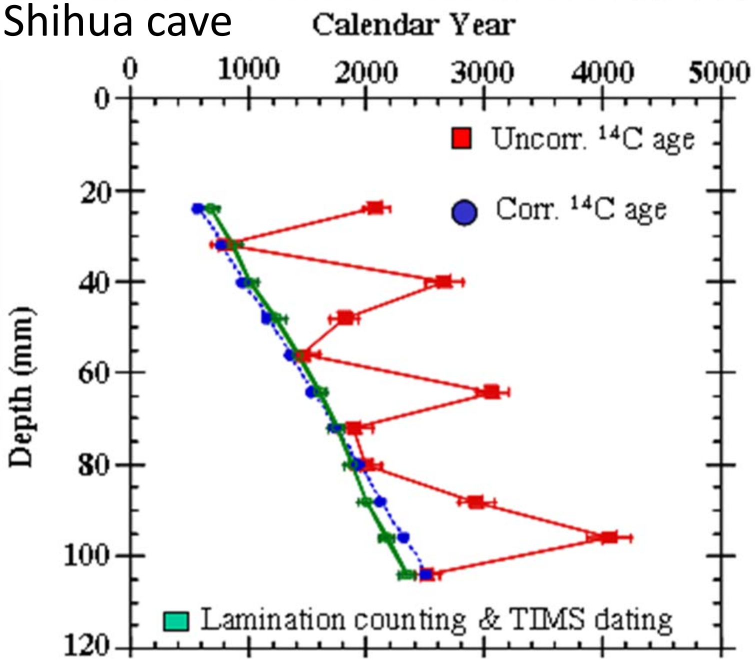
Stalagmite

Panlong Cave



S312

Shihua cave



石筍樣品測試

鈾釷質譜定年

	(mm)	^{238}U ppb	^{232}Th ppt	$[^{230}Th/^{232}Th]$ ppm^{d}	Age uncorrected	Age corrected ^{c,e}
DGS-1-01	**1~3**	**1453.7 ± 2166.2**	**80658 ± 120196**	**13 ± 28**	**4,716 ± 10184**	**3,302 ± 9054**
DGS-1-02	**50~52**	**3719.8 ± 10.3**	**81499 ± 1180**	**14 ± 1**	**1,938 ± 77**	**1,380 ± 565**
DGS-1-03	**111~113**	**3926.1 ± 11.1**	**266038 ± 5013**	**18 ± 1**	**8,182 ± 254**	**6,457 ± 1757**

Sample ID	Depth (mm)	Weight (mg)	C (mg)	^{12}C current (A)	^{14}C Counts	^{14}C error (%)	^{14}C / ^{12}C Ratio	^{14}C age
DGS2	25	15.45	0.40	1.54E-08	26	19.61	5.139E-13	3555 ± 697
DGS3	42.5	15.06	1.79	2.04E-07	719	3.73	5.381E-13	3178 ± 119
DGS4	66	15.93	1.89	1.72E-07	603	4.07	5.354E-13	3218 ± 131
DGS5	82	14.56	1.69	1.95E-07	692	3.80	5.406E-13	3142 ± 119
DGS6	98.5	16.74	0.30	3.45E-08	89	10.60	3.941E-13	5699 ± 604
DGS7	122	14.65	1.76	2.14E-07	666	3.88	4.749E-13	4188 ± 162
DGS8	140	14.69	1.71	2.07E-07	709	3.76	5.224E-13	3418 ± 128

Summary

- The HVE 1.0MV AMS at NTU is capable for ^{14}C, ^{10}Be and ^{26}Al measurements. The detection limits for $^{14}C/^{12}C$, $^{10}Be/^{9}Be$ and $^{26}Al/^{27}Al$ are 10^{-15}, 10^{-14} and 10^{-14}, respectively.
- Our graphitization line can treat six samples each time, and is able to deal with both carbonates and organic matters.
- The Li_2^{++} interference problem has been solved, by adjusting slits and gas pressure or by using $^{14}C^{+++}$.
- The international standards (OXI, OXII and ANU) have been measured, resulting correct values.

Summary (Cont.)

- A carbonate background (NTUB) which is from the upper Devonian limestone in Guilin of China, and a fossil wood background (CWOC) that is from the middle Pleistocene deposits in central Taiwan have been tested. The results show that both backgrounds have the $^{14}C/^{12}C$ ratios of ~$3.2X10^{-15}$ which is close to the AMS background.
- The AMS at NTUAMS Lab is ready to serve ^{14}C dating.