Adopted Levels, Gammas

Q(β^-)=1.181×10^4 *4*; S(n)=4.18×10^3 *3*; S(p)=2.609×10^4 *21*; Q(α)=−1.746×10^4 *14* 2017Wa10

Theoretical analysis:

See discussion on N-N interactions and pairing effects in (1997Po14, 2000De24, 2002Gr14, 2007Ma53, 2008Ha17, 2012Ha21, 2012Id04, 2012Yu04, 2013Sh17, 2016La17, 2017Me03).

See discussion on the nuclear radius of ^{18}C in (1971St40, 1992La13, 1993Po11, 1996Sh13, 1996Su24, 2001Go24, 2002Me12, 2004Ya05, 2008Ca29, 2009Ch45, 2009Pa46, 2010Ca15, 2011Al11, 2011Fo18, 2016Fo24).

Other general shell-model, potential-model and cluster-model analyses of ground-state energies, excited state energies, moments, deformation lengths, etc. can be found in (1964In03, 1971Fi11, 1987Bl18, 1993Pa14, 1995Ho13, 1996Gr21, 1996Ka14, 1996Re19, 1997Ba54, 1997Ho04, 1998Sh16, 1999Ha61, 1999Sh16, 2001Ka66, 2002Ka73, 2003Sa50, 2003Su09, 2003Th06, 2004Th11, 2005Ga31, 2005Ka54, 2006Ko02, 2006Le33, 2006Sa29, 2006Ta28, 2009Pu01, 2010Co05, 2011Co18, 2013Lu02, 2014Eb02, 2014Ja14, 2014Ro22, 2014Sa13, 2015Ka02, 2015Sh21).

2010Ya03: The authors utilized a ^{16}C+n+n 3-body model to analyze levels that could participate in the ^{17}C(n,γ)^{18}C reaction under the condisions of a core-collapse supernovae, where ^{18}C is suggested as a semi-waiting point for *r*-process nucleosynthesis. See additional references in the text.

2011Ba01: The authors analyze the probability for population of ^{18}C states in β-delayed proton emission events from ^{19}C where the halo neutron is converted to a proton and then emitted.

Other Experimental Work:

2017He04: E(^{18}C)=425 MeV/nucleon, Pb target, Coulomb dissociation, σ's to ^{17}C*(0,0.22,0.33 MeV).

1995Ba28: E(^{18}C)≈86.2 MeV/nucleon, Be target, FWHM(^{17}C parallel momentum dist)$_{lab}$=110 MeV/c *12*, σ_{1n}=34.8 mb *21*. See also 1997Or03.

2000Sa47: E(^{18}C)=47 MeV/nucleon, carbon target,FWHM(^{17}C parallel momentum dist)$_{lab}$=126 MeV/c *5*, σ_{1n}=115 mb *18*. The authors suggest Jπ=0$^+$.

2001Oz03: E(^{18}C)=955 MeV/nucleon, carbon target, $\sigma_{interaction}$=1104 mb *15*, analyzed relation of σ_i to effective matter radius: R_{rms}≈2.82 fm *4*.

See also results on ^{18}C fragment momentum distributions from the breakup of heavier projectiles in (2011Oz01, 2012Ko38, 2015Mo17).

^{18}C Levels

Cross Reference (XREF) Flags

A	^{1}H(^{19}C,^{18}Cγ)	E	^{9}Be(^{48}Ca,^{18}C)	I	^{48}Ca(^{18}O,^{18}C)
B	^{9}Be(^{18}C,^{18}C′γ)	F	^{18}O(π^-,π^+)	J	^{232}Th(^{18}O,^{18}C)
C	^{9}Be(^{19}N,^{18}Cγ)	G	C(^{36}S,Xγ)	K	^{232}Th(^{22}Ne,^{18}C)
D	^{9}Be(^{40}Ar,^{18}C)	H	^{19}B β^-n decay	L	U(p,^{18}C),(n,^{18}C)

E(level)[†]	J^π	$T_{1/2}$	XREF	Comments
0.0	0$^+$	92 ms *2*	ABCDEFGHIJKL	%β^-=100; %β^-n=31.5 *15* (1995ReZZ) T=3 $T_{1/2}$: from 1995Sc03. Others: 66 ms *+25−15* (1988Mu08), 78 ms *+20−15* (1989Le16), 95 ms *10* (1991Pr03), 92 ms 5 (2008ReZZ, see also 1991Re02, 2005ReZZ). See also 2012Ch48.
1588 *8*	2$^+$	15.5 ps *25*	ABC FG I	T=3 $T_{1/2}$: from 2012Vo05. Others: 13.1 ps *31* (2009On02).
2515 *10*	(2$^+$)	<3.2 ps	ABC G	T=3 $T_{1/2}$: from 2012Vo05.
3972 *20*	(2,3)$^+$		AB G	T=3

[†] From analysis of γ-rays in (2008St18, 2009Ko02, 2012Vo05).

Adopted Levels, Gammas (continued)

$\gamma(^{18}C)$

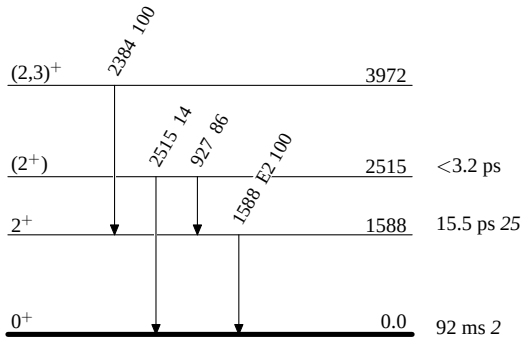
E_i(level)	J_i^π	E_γ †	I_γ	E_f	J_f^π	Mult.	Comments
1588	2^+	1588 *8*	100	0.0	0^+	E2	B(E2)=0.000364 *+15−14*(stat) *+40−47*(syst).
2515	(2^+)	927 *7*	86 *12*	1588	2^+		
		2515 *30*	14 *12*	0.0	0^+		
3972	$(2,3)^+$	2384 *17*	100	1588	2^+		

† From analysis of γ-rays in (2008St18, 2009Ko02, 2012Vo05).

Adopted Levels, Gammas

Level Scheme

Intensities: % photon branching from each level



$^{18}_{6}C_{12}$

^{1}H(^{19}C,^{18}Cγ) 2009Ko02

The authors produced a E(^{19}C)=81 MeV/nucleon beam by fragmenting ^{22}Ne ions at the RIKEN/RIPS facility. The beam impinged on a 120 mg/cm^2 liquid hydrogen target an the CRYPTA (cryogenic proton/α) target system. The trajectory of the incident beam on target was measured, and the outgoing particles were momentum analyzed using a large acceptance magnetic spectrometer that selected ^{18}C particles following one-neutron removal. In addition, the 48 NaI crystal DALI γ-ray array surrounded the hydrogen target and measured γ-rays in coincidence with the ^{18}C fragments. Three γ-ray transitions were observed in coincidence with ^{18}C particles in the focal plane; the deduced level scheme is understood based on known levels.

In the analysis, transverse momentum distributions of ^{18}C reaction products were generated for coincidences with each of the γ transitions. The momentum distributions were then evaluated, via CDCC analysis, to obtain l values of the removed neutrons from ^{19}C.

^{18}C Levels

E(level)	J^{π} †	l ‡
0	0^+	0
1600	2^+	2
2500	$(0,2)^+$	0,2
4000	$(2,3)^+$	2

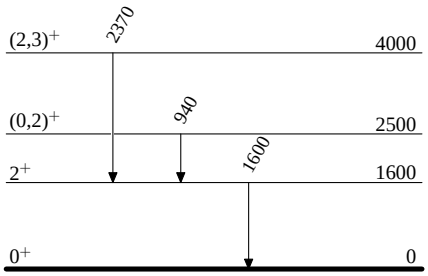
† From shell model expectations.
‡ Orbital angular momentum of removed neutron.

γ(^{18}C)

E_γ	E_i(level)	J_i^{π}	E_f	J_f^{π}
940 *20*	2500	$(0,2)^+$	1600	2^+
1600 *20*	1600	2^+	0	0^+
2370 *20*	4000	$(2,3)^+$	1600	2^+

^{1}H(^{19}C,^{18}Cγ) 2009Ko02

Level Scheme



$^{18}_{6}C_{12}$

^{9}Be(^{18}C,^{18}C′γ) 2008On02,2009On02

Produced E(^{18}C)=79 MeV/nucleon beam using the ^{9}Be(^{22}Ne,X) at the RIPS/RIKEN facility. Event-by-event particle identification of the secondary beam was obtained by ΔE-time-of-flight between two 1 mm thick plastic scintillators, and the trajectory onto the ^{9}Be target was tracked using two parallel plate avalanche counters. The lifetime of first 2^+ state was measured using the recoil shadow method; γ rays were detected using an array of 130 NaI(Tl) detectors. After the target, the residual nuclides were detected using a plastic scintillator hodoscope.

See detailed theoretical discussion on the E2 transition from the first excited state, which is anomolously hindered, in (1997Ka25, 2004La24, 2004Sa58, 2004Su23, 2005Ka03, 2005Sa63, 2008Um02, 2008Zh16, 2009Su17, 2009Um05, 2009Yu07, 2011Ya11, 2012Yu07, 2013Fo11, 2013Ka33, 2014Ma97, 2016Pr01).

^{18}C Levels

E(level)	J^π	$T_{1/2}$	Comments
0	0^+		
1585 *10*	(2^+)	13.1 ps *31*	$T_{1/2}$: from (2008On02, 2009On02), recoil-shadow method. The statistical uncertainty of 0.9 ps and systematic uncertainty of 4.4 ps in mean lifetime were combined in quadrature.
2504 *14*			A g.s. transition is shown in the level/transition diagram of 2009On02 but is absent in 2008On02. The measured spectrum does not show strong support for this transition.
4000? *32*			E(level): probably taken from 2008St18.

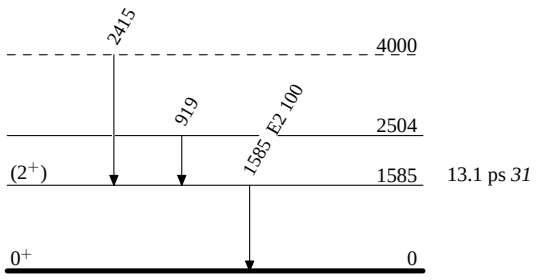
γ(^{18}C)

E_i(level)	J_i^π	E_γ	I_γ	E_f	J_f^π	Mult.	Comments
1585	(2^+)	1585 *10*	100	0	0^+	E2	B(E2)(W.u.)=1.5 *4*
2504		919		1585	(2^+)		
4000?		2415		1585	(2^+)		Shown in 2008On02, but not in 2009On02. The measured spectrum may show weak support for this transition.

^{9}Be(^{18}C,^{18}C′γ) 2008On02,2009On02

Level Scheme

Intensities: Relative photon branching from each level



$^{18}_{6}C_{12}$

^{9}Be(^{19}N,^{18}Cγ) 2012Vo05

The authors measured the lifetime of the first two excited states of ^{18}C.

Neutron rich ^{18}C ions were produced at the NSCL in a multistep process, first by fragmenting a 120 MeV/nucleon ^{22}Ne beam in a 1763 mg/cm^2 ^{9}Be target to produce a $\Delta p/p$=0.7% momentum analyzed 72 MeV/nucleon ^{19}N beam. The ^{19}N beam then impinged on a 196 mg/cm^2 ^{9}Be target where ^{18}C ions were produced in ground and excited states via 1-proton knockout reactions. Transitions from the $J\pi=2^+_{1,2}$ states are observed with a relative production ratio of 4: 1, respectively.

The lifetimes were determined using the recoil distance method (see for example 2008De30). A 2.01 g/cm^2 ^{181}Ta degrader foil was placed downstream of the 196 mg/cm^2 ^{9}Be reaction foil; γ-rays emitted before/after the degrader foil experience different Doppler shifts and the state lifetime can be deduced from the ratio (v/c_i=0.3565 and $v/c_f\approx$0.2920). Reactions in the Ta degrader foil introduce a systematic error.

Finally, discussion indicates strong evidence that the inclusion of three-body forces is needed to describe the low-lying excited-state properties of this A=18 system.

^{18}C Levels

E(level)	J^π	$T_{1/2}$	Comments
0	0^+		
1585 *19*	2^+	15.5 ps *25*	The mean lifetime τ=22.4 ps *9*(stat) *+33−22*(syst) is deduced corresponding to $T_{1/2}$=15.5 ps *6*(stat) *+23−15*(syst).
2517 *22*	(2^+)	<3.2 ps	The mean lifetime τ<4.6 ps is deduced corresponding to $T_{1/2}$<3.2 ps.

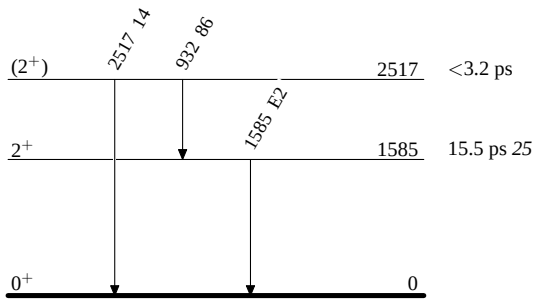
γ(^{18}C)

E_i(level)	J^π_i	E_γ	I_γ	E_f	J^π_f	Mult.	Comments
1585	2^+	1585 *19*		0	0^+	E2	B(E2)=0.000364 *+15−14*(stat) *+40−47*(syst).
2517	(2^+)	932 *11*	86 *12*	1585	2^+		
		2517 *30*	14 *12*	0	0^+		

^{9}Be(^{19}N,^{18}Cγ) 2012Vo05

Level Scheme

Intensities: % photon branching from each level



$^{18}_{6}C_{12}$

^{9}Be(^{40}Ar,^{18}C) 2000Oz01,2012Kw02

2000Oz01: Production yields for fragmentation of 1 GeV/nucleon ^{40}Ar projectiles on a berylium target were measured. Cross sections of roughly 3.34×10^{-6} b were deduced.

2012Kw02: Production yields for fragmentation of 120 MeV/nucleon ^{40}Ar projectiles on berylium, nickel and tantalum targets were measured. The cross section of roughly 2×10^{-3} mb was deduced for ^{9}Be.

^{18}C Levels

E(level)
0

^{9}Be(^{48}Ca,^{18}C) 1981St23

1981St23: Production yields for fragmentation of 213 GeV/nucleon ^{48}Ca projectiles on a berylium target were measured at the Bevalac using a 0° magnetic spectrometer. The neutron-rich fragments were focused on a stack of Lexan plastic track detectors; analysis of the tracks provided the range, charge and magnetic deflection of the produced isotopes. A charge resolution of 0.2 was obtained along with a mass resolution of approximately ≤0.2 u.

The analysis showed clear indications of ^{18}C, ^{19}C, ^{20}C. Ambiguous results on ^{21}C are found. This work is credited with the discover of ^{20}C and ^{27}F. For ^{18}C, the cross section of roughly 10 μb was deduced.

^{18}C Levels

E(level)
0

^{18}O(π^-,π^+) 1978Se07,1984Gi10

1978Se07: The mass of ^{18}C was measured using the (π^-,π^+) double-charge-exchange reaction. A beam of 164 MeV negative pions from the LAMPF EPICS facility impinged on a refrigerated 0.90 g/cm^2 94.8% ^{18}O enriched ice target. The outgoing π^+ particles were momentum analyzed using a triple-quadrupole-double-dipole magnetic spectrometer that was calibrated using the ^{12}C(π^-,π^+)^{12}Be reaction. The value Q=−25.69 MeV *15* is deduced for the reaction. The present value for ΔM(^{18}O)=−782.8156 keV *7*, which is consistent with the 1974 value, gives ΔM=24.91 MeV *15*.

1984Gi10: In a follow-up measurement to 1978Se07 at LAMPF, the systematics of ^{18}O(π^-,π^+)^{18}C$_{g.s.}$ and ^{18}O(π^+,π^-)^{18}Ne$_{g.s.}$ reactions are compared using a refrigerated 0.91 g/cm^2 94% ^{18}O enriched ice target. In this case evidence was observed for a state at E$_x$=1.55 MeV.

See also discussion in 1980Ge09.

^{18}C Levels

E(level)	Comments
0	ΔM=24.91 MeV *15* is deduced.
1.55×10^3	

C(^{36}S,Xγ) 2008St18,2004St10

2004St10,2004ST29,2008ST18: Two-step fragmentation reaction. The authors populated ^{18}C using a cocktail beam of neutron-rich nuclides [^{25}Ne, ^{26}Ne, ^{27}Na, ^{28}Na, ^{29}Mg, and ^{30}Mg] that were produced by fragmenting an initial 77.5 MeV/nucleon ^{36}S beam at the GANIL/SISSI beamline. The cocktail beam was selected using the α spectrometer and focused on a carbon target that was coupled to a plastic scintillator.

Eγ, $\gamma\gamma$, γ(fragment) coincidences were measured using 74 BaF_2 detectors that surrounded the target with 4π and the SPEG spectrometer. The ^{18}C were identified using time-of-flight, energy loss and focal-plane position information. The γ-ray transitions are observed. Results are compared with shell-model calculations for analysis of Jπ values.

All data are from 2008St18.

^{18}C Levels

E(level)	J$^\pi$	Comments
0	0$^+$	
1585 *10*	2$^+$	J$^\pi$: from systematics of e-e nuclei and shell-model predictions.
2504 *14*		
4000 *32*		

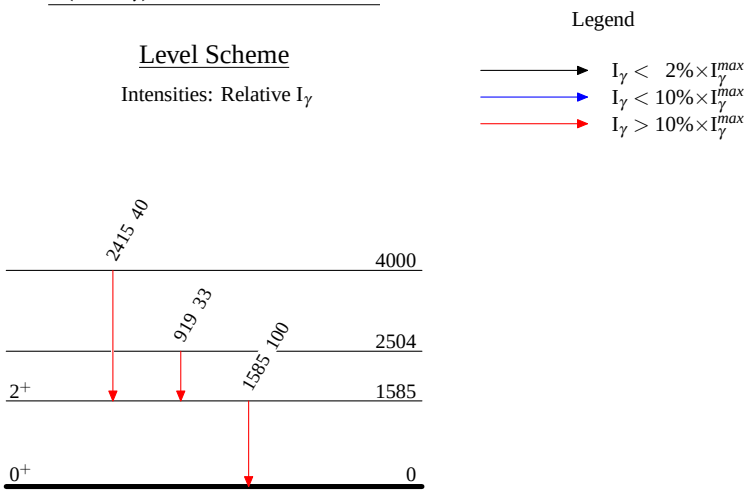
γ(^{18}C)

E$_\gamma$	I$_\gamma$	E$_i$(level)	J$_i^\pi$	E$_f$	J$_f^\pi$
919 *10*	33 *8*	2504		1585	2$^+$
1585 *10*	100 *5*	1585	2$^+$	0	0$^+$
2415 *30*	40 *9*	4000		1585	2$^+$

C(^{36}S,Xγ) 2008St18,2004St10

Level Scheme

Intensities: Relative I$_\gamma$



$^{18}_{6}C_{12}$

^{19}B β^-n decay 1998Yo06,2003Yo02

Parent: ^{19}B: E=0; J^π=(3/2$^-$); $T_{1/2}$=2.92 ms *13*; Q(β^-n)=2.579×10^4 *43*; %β^-n decay=72 *8*

^{19}B-$T_{1/2}$: from 2003Yo02.

^{19}B-Q(β^-n): from 2012Wa38.

1998Yo06: A beam of ^{19}B was produced by fragmentation of a 95 MeV/nucleon ^{40}Ar beam on a ^{181}Ta target. ^{19}B was selected using the RIKEN Projectile-fragment Separator (RIPS) and was implanted into a 12 mm thick plastic scintillator stopper. The β-decays were observed during the 100 ms beam-off period. The active stopper detected β-rays and a neutron detector array, consisting of 14 liquid scintillation counters covering about 80% of 4π detected delayed neutrons. The efficiency of the neutron array was 30% by comparison of a measurement of β-delayed neutrons of ^{15}B, which has a known delayed neutron emission probability of 100%.

A preliminary value of $T_{1/2}$=3.3 ms *2* was dedcued from the least-squares fits to the data, and P_n=125% *32* was determined from the ratio of the number of detected neutrons to that of β-rays. P_n is more than 100% which implies the existence of significant multineutron emissions in the decay, reflecting its large Q_β value (26.5 MeV) compared with the multineutron separation energies of daughter nucleus ^{19}C (S_{1n}=160 keV, S_{2n}=4.4 MeV,.....).

2003Yo02: The authors reevaluated the preliminary values $T_{1/2}$ and P_n reported in 1998Yo06. The new experiment was performed using RIPS at RIKEN Accelerator Research Facility as was in 1998Yo06. A beam of ^{19}B was produced by the projectile-fragmentation reaction of a 95 MeV/*u* ^{40}Ar beam on a 670 mg/cm^2 ^{nat}Ta target. The values of $T_{1/2}$ and P_{in} were determined by fitting a set of decay curves altogether to remove possible complication and inconsistency. The method of maximum likelihood was applied for deducing $T_{1/2}$ and P_{in}. The neutron detection efficiencies were treated carefully, the total detection efficiencies of direct and scattered neutrons are 31.5% *3* and 4.7% *+2-6*, respectively. The new values of $T_{1/2}$=2.92 ms *13*, P_{1n}=71.8% *+83-91* and P_{2n}=16.0% *+56−48* were determined with a better precision. P_{3n} was not determined because of the limited statistics. In the text it is unclear if the 1998Yo06 "preliminary" data are included in the 2003Yo02 analysis; we assume that it is and use the 2003Yo02 result to avoid possible data correlations.

1999Re16: A low statistics determination of $T_{1/2}$=4.5 ms *15* was given.

^{18}C Levels

E(level)	J^π[†]	$T_{1/2}$[†]
0.0	(0$^+$)	92 ms *2*

[†] From Adopted dataset for ^{18}C in ENSDF database.

Delayed Neutrons (^{18}C)

E(^{18}C)	I(n)	Comments
0.0	71.8 *83*	In=71.8 *+83−91*.

^{48}Ca(^{18}O,^{18}C) 1982Fi10

1982Fi10: The mass and excitation spectrum of ^{18}C were determined using the ^{48}Ca(^{18}O,^{18}C) reaction. A beam of 112 MeV ^{18}O ions, from the Australian National University pelletron accelerator, impinged on a 97% enriched 100μg/cm^2 ^{48}Ca target. The ^{18}C reaction products were detected at θ=50° using an Enge split-pole spectrometer. Peaks corresponding to states in ^{18}C and ^{48}Ti are observed and discussed. The Q-value (−21434 keV *30*) was deduced, which corresponds to ΔM=24923 keV *30*.

1982Na04: An earlier rapid communication was published that reported on a mass measurement carried out at Orsay. A 100 MeV ^{18}O beam impinged on a 1.3 mg/cm^2 ^{48}C target and the reaction products were momentum analyzed using a magnetic spectrometer. $^{18}C_{g.s}$ and ^{48}Ti*(984 keV) were observed. The Q-value −21.33 MeV *30* was measured, which yields ΔM=24.82 MeV *30* and is consistent with prior results.

^{18}C Levels

E(level)	Comments
0	ΔM=24923 keV *30* is deduced in 1982Fi10.
1620 *20*	E(level): from 1982Fi10.

^{232}Th(^{18}O,^{18}C) 1969Ar13

1969Ar13: The discovery of ^{18}C is credited to 1969Ar13, who analyzed the transfer reaction products resulting from E(^{18}O)=122 MeV bombardment of a 5 mg/cm^2 metalic ^{232}Th foil at Dubna. The reaction products were momentum analyzed in a magnetic spectrometer and then focused on a ΔE-E Si detector telescope, which provided particle identification.

^{18}C Levels

E(level)
0

^{232}Th(^{22}Ne,^{18}C) 1977Ar06

1977Ar06: The transfer reaction products resulting from E(^{22}Ne)=172 MeV bombardment of a 2.5 mg/cm^2 metalic ^{232}Th foil were measured at Dubna. The reaction products were momentum analyzed in a magnetic spectrometer positioned at θ=12° and 40° and then focused on a ΔE-E Si detector telescope, which provided particle identification.

^{18}C Levels

E(level)
0

U(p,^{18}C),(n,^{18}C) 1970Bu22

1970Bu22: The particle stability of ^{18}C was confirmed at the Bevatron by 1970Bu22 who analyzed the spallation products emitted in the 5.5 GeV proton bombardment of a $^{nat.}$U target. The reaction products were detected in a set of Si detectors that were placed at θ=90° with respect to the incident beam. The two detectors, which provided ΔE and E signals were located at distances of 14.5 cm and 25.7 cm from the target. Particle identification was unambiguously determeined by evaluating ΔE, E and the time-of-flight between the detectors.

1974Bo05: Similar to 1970Bu22, spallation products emitted in the 4.8 GeV proton bombardment of a $^{nat.}$U target were analyzed in a survey of bound light neutron rich nuclei in the A=14-22 mass region. Evidence of A=10-19 isotopes of carbon was observed. A ^{18}C production cross section of ≈100 μb was measured.

1986Pi09: Spallation products from 800 MeV proton bombardment of a uranium target at LAMPF were detected using a series of detectors that provided ΔE, E and time-of-flight information. The products were analyzed to obtain A and Z identification, and mass excesses were obtained for a few carbon, nitrogen, oxygen, florine and neon isotopes. ΔM=22.7 MeV 80 was obtained for ^{18}C.

1986Do08: The yields of various He, Li, Be, B, C, O and Ne isotopes – including ^{18}C, produced via thermal neutron induced fission reactions on ^{235}U at the ILL, were determined. The fission fragments were magnetically analyzed in the Lohengrin spectrometer and detected in a ΔE-E telescope.

^{18}C Levels

E(level)
0

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