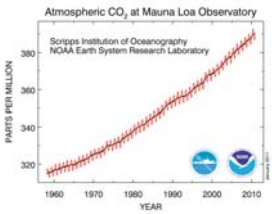
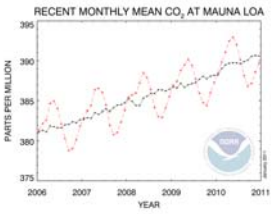
What can you measure with neutron activation analysis?

Chris Waring, Sascha Falahat, Geoff Watt
Institute for Environmental Research
Australian Nuclear Science and Technology Organisation

Seasonal CO_2 plant & soil uptake & release





SMH 15/4/2011

"It would equate to a new rural industry for Australia, as big as the wool industry was last year" Prof. Garnaut

AGRICULTURE

Carbon storage to rival wool, says Garnaut

Ben Cubby
environment editor

STORING carbon dioxide in the landscape has the potential to be as important to the rural economy in 2020 as the entire Australian wool industry, the federal government's climate change adviser, Ross Garnaut, believes.

Professor Garnaut addressed a public meeting in Armidale last night at the invitation of the independent MP Tony Windsor, a member of the government's ...

Some farmers respond to an opportunity and their neighbours notice.'

Ross Garnaut

Picture this ... Tim Wright, right, tells Ross Garnaut and Tony Windsor about carbon storage on his property. Photo: Dan Schneider

Motivation

The Australian Government is likely to adopt a scheme to pay farmers carbon credits for sequestered Carbon called the Carbon Farming Initiative (CFI) with a proposed start date of July 1 2011.

Storing Carbon in soils and agro-forestry are likely to provide the most scope for farmers to receive payment of carbon credits under the CFI.

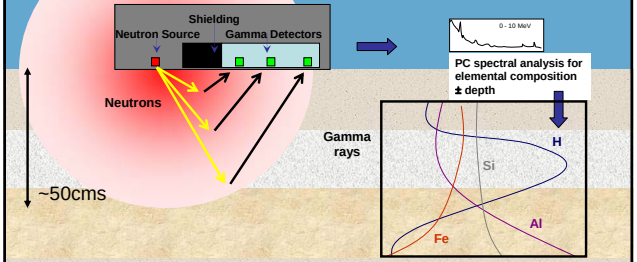
Under the integrity standards of the CFI scheme it is important to ensure that all abatement credited is real and verifiable. The following criteria must be met.

- **Additional** (differential measurement, how long, from what to what?)
- **Permanent** (what C species?, decay or build up parameters?)
- **Avoidance of leakage** (organic C, biochar decay model?, CO_2 + CH_4 gas flux?)
- **Measurable and verifiable** (method accuracy, combined analysis + sampling error)
- **Conservative** (model parameter choice + differential measurement error = no payment)
- **Supported by peer-reviewed science** (new site always different from study site)

Existing soil carbon measurement technologies cannot cost-effectively meet the CFI criteria due to soil heterogeneity = sampling error.

Neutron Activation for Carbon, soil moisture & composition (H, O, C, Si, Al, Fe, +)

ANSTO is developing a field instrument for soil scanning & composition mapping

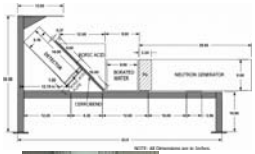


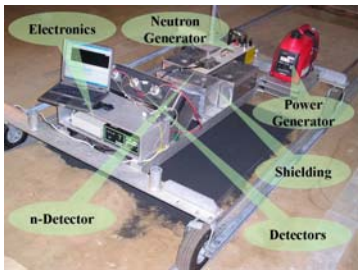
Carbon requires neutron generator (D-T fusion, 14 MeV neutrons, INS not PGNA)

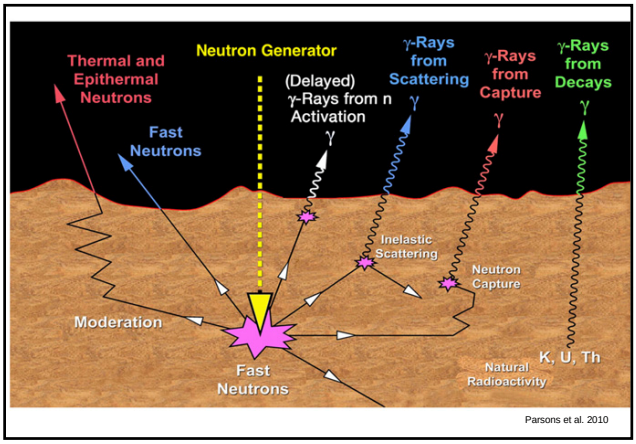
Unique instrument for remote soil geochemical measurement

Brookhaven National Lab. has built proof of concept soil C instrument

MDL of the INS system at the 3σ (99%) confidence level and 30-min counting time is about 0.004 to 0.008 g C cm^{-3}
Wielopolski, 2008





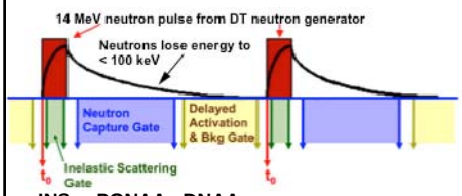


Neutron capture cross-section

neutrons/cm^2 x cross-section x abundance = γ photons

Element (atomic mass)	Thermal neutron capture cross-section (barns)	Major gamma-rays (MeV)	Gamma-ray intensity (per 100 neutron radiative captures)
Hydrogen (1.0079)	0.3326	2.223	100
Carbon (12.0107)	0.00337	1.26 3.68 4.94	29.5 32.1 67.6
Iron (55.85)	2.55	5.92 6.02 7.63 7.65	9 9 24.1 28.5
Silicon (28.09)	0.16	1.16 2.09 3.54 4.93 6.38	19.9 21.5 68.0 62.7 12.4
Aluminium (26.98)	0.23	7.72	27.4
Calcium (40.08)	0.43	1.94 4.42 6.42	72.6 15.0 38.9
Sulphur (32.06)	3.32	0.84 2.38 2.93 3.22 5.42	75.6 44.5 22.3 27.1 59.1
Gadolinium (157.25)	7,680	0.182 1.186	

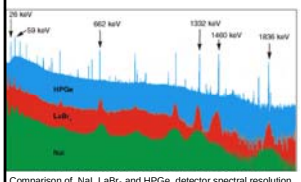
Neutron Generators



INS PGNAA DNAA

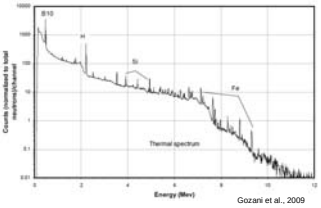
- **Mini accelerators give nuclear fusion reaction D + T = n + α**
- **Existing neutron generators have an output limit of 1x10^8 n/s**
- **Probably need an output of 1x10^{10} n/s for rapid field scanning**

Gamma Detectors



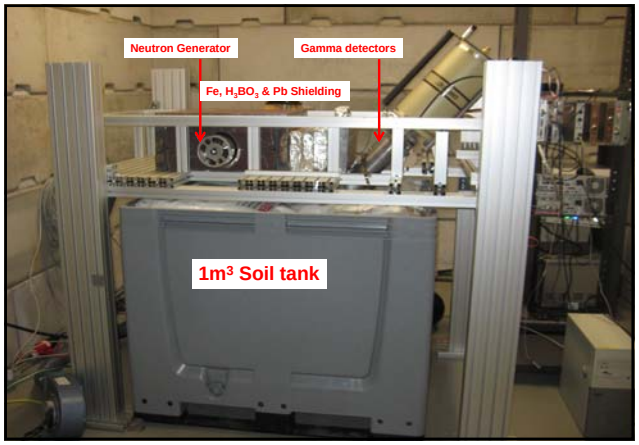
Comparison of NaI, $LaBr_3$ and HPGe detector spectral resolution

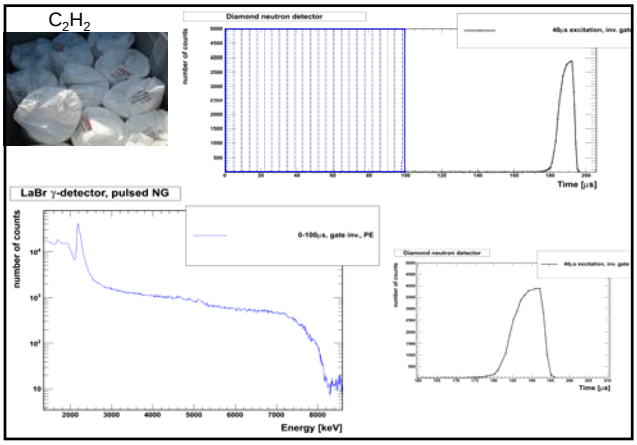
High Resolution Ge detector 16% moist clay soil
Capture (PGNAA = TNA) spectrum

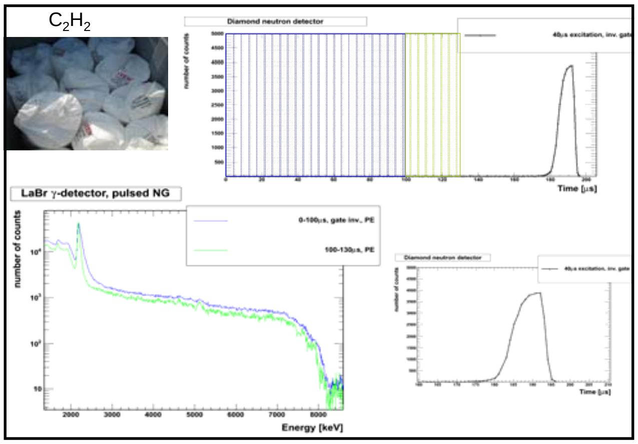


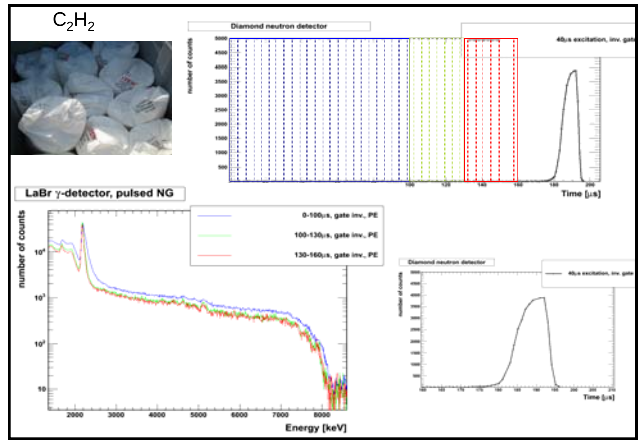
Gozani et al., 2009

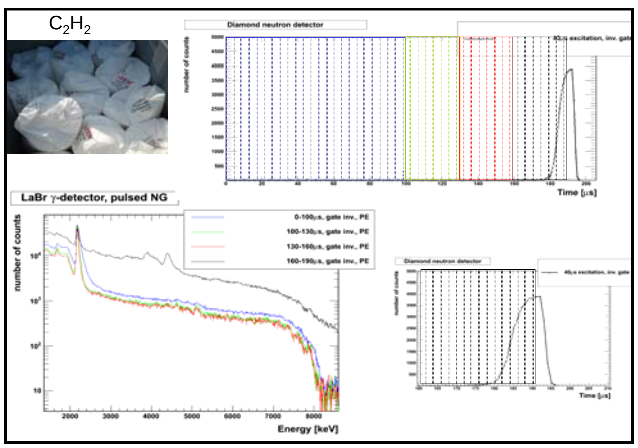
- **Trade off between cost, resolution, speed, durability & efficiency**
- **Different detectors suited to different applications**
  eg rapid scan of abundant element Si, C, = large volume NaI
  static long count time trace element S, N, = HPGe

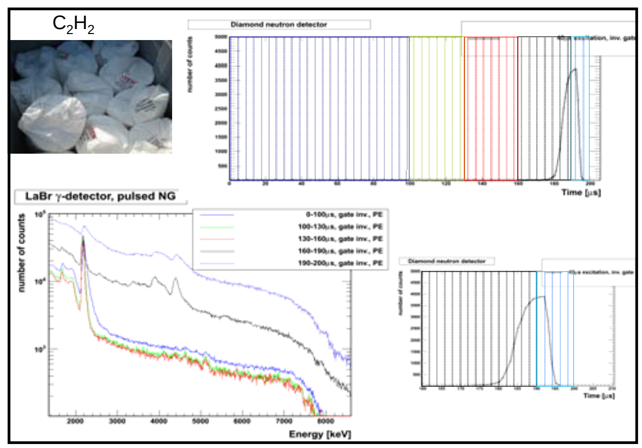


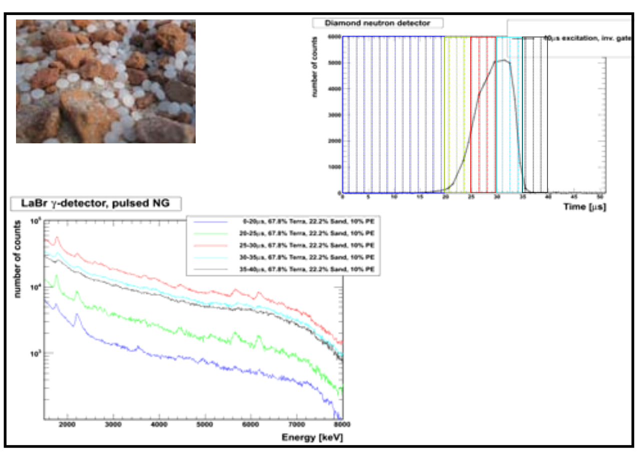


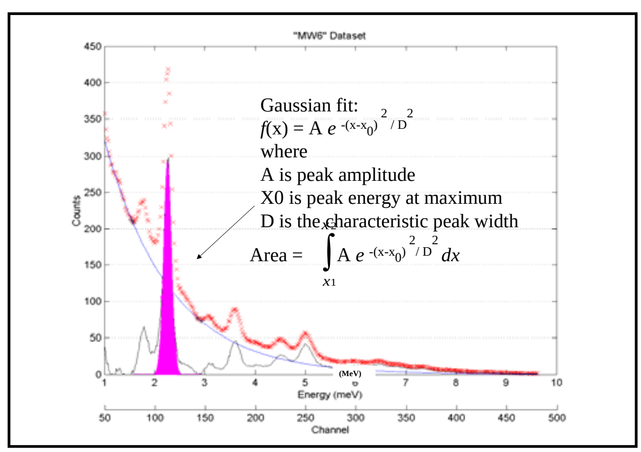

C2H2
Diamond neutron detector
40μs excitation, inv. gate
Time [μs]
LaBr γ-detector, pulsed NG
number of counts
0-100μs, gate inv., PE
100-130μs, gate inv., PE
Energy [keV]

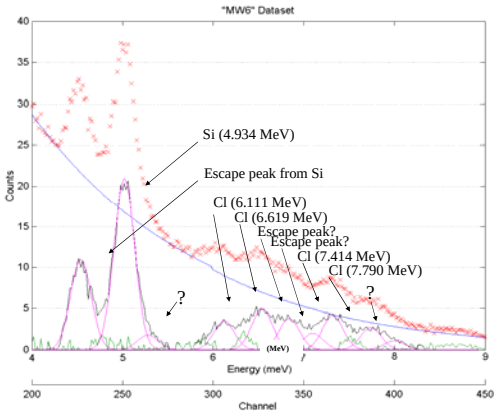

C2H2
Diamond neutron detector
40μs excitation, inv. gate
Time [μs]
LaBr γ-detector, pulsed NG
number of counts
0-100μs, gate inv., PE
100-130μs, gate inv., PE
130-160μs, gate inv., PE
Energy [keV]


C2H2
Diamond neutron detector
Time [μs]
LaBr γ-detector, pulsed NG
number of counts
0-100μs, gate inv., PE
100-130μs, gate inv., PE
130-160μs, gate inv., PE
160-190μs, gate inv., PE
Energy [keV]


C2H2
Diamond neutron detector
Time [μs]
LaBr γ-detector, pulsed NG
number of counts
0-100μs, gate inv., PE
100-130μs, gate inv., PE
130-160μs, gate inv., PE
160-190μs, gate inv., PE
190-200μs, gate inv., PE
Energy [keV]


Diamond neutron detector
40μs excitation, inv. gate
Time [μs]
LaBr γ-detector, pulsed NG
number of counts
Energy [keV]


"MW6" Dataset
Gaussian fit:
f(x) = A e -(x-x0)^2 / D^2
where
A is peak amplitude
X0 is peak energy at maximum
D is the characteristic peak width
Area = ∫ A e -(x-x0)^2 / D^2 dx
Counts
Energy (meV)
Channel



What can neutron activation measure?

Now static measurement 3 – 30 mins

- Carbon (MDL 0.5 % Wielopolski BNL)
- Acquires spectra representative to a depth of ~0.5m;
- Homogenises large soil volume (~0.5 m^3) per analysis for good statistical sampling;
- Quantitative measurement of C, O by INS and H, Si, Al, Fe, Cl, ++ and many important trace elements (S, N) by PGNAA for a total soil composition
- Soil C sequestration, soil moisture mapping, nutrient mobility & precision fertilizer application

Future milestones

- Our objective is to develop a field instrument for high-resolution soil composition mapping = surface scanning
  - Improve neutron generator output from 10^8 to 10^{10} n/s
  - Optimise detector array, type & volume for each element
  - Improve gamma spectroscopy
- Design and construction of commercial mobile field unit to satisfy Carbon & compositional measurement demand