BROOKHAVEN
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BNL-72200-2004
FORMAL REPORT

Non-Destructive Soil Carbon Analyzer (ND-SCA)
Progress Report

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February 2004

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NON-DESTRUCTIVE SOIL CARBON ANALYZER

(ND – SCA)

To The DOE/OBER/TCP
Program Manager

Submitted by

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Acknowledgement: The contributions of N. Foster, A. Hanson, B. Dorman, and J Carrington are appreciated. This research was performed under the auspices of the U.S. Department of Energy Office of Science Contract No. DE-AC02-98CH10886 to Brookhaven National Laboratory.

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1. SUMMARY

This report describes the feasibility, calibration, and safety considerations of a non-destructive, *in situ*, quantitative, volumetric soil carbon analytical method based on inelastic neutron scattering (INS). The method can quantify values as low as 0.018 gC/cc, or about 1.2% carbon by weight with high precision under the instrument's configuration and operating conditions reported here. INS is safe and easy to use, residual soil activation declines to background values in under an hour, and no radiological requirements are needed for transporting the instrument. The labor required to obtain soil-carbon data is about 10-fold less than with other methods, and the instrument offers a nearly instantaneous rate of output of carbon-content values. Furthermore, it has the potential to quantify other elements, particularly nitrogen.

New instrumentation was developed in response to a research solicitation from the U.S. Department of Energy (DOE LAB 00-09 Carbon Sequestration Research Program) supporting the Terrestrial Carbon Processes (TCP) program of the Office of Science, Biological and Environmental Research (BER). The solicitation called for developing and demonstrating novel techniques for quantitatively measuring changes in soil carbon. The report includes raw data and analyses of a set of proof-of-concept, double-blind studies to evaluate the INS approach in the first phase of developing the instrument.

Managing soils so that they sequester massive amounts of carbon was suggested as a means to mitigate the atmospheric buildup of anthropogenic CO_2. Quantifying changes in the soils' carbon stocks will be essential to evaluating such schemes and documenting their performance. Current methods for quantifying carbon in soil by excavation and core sampling are invasive, slow, labor-intensive and locally destroy the system being observed. Newly emerging technologies, such as Laser Induced Breakdown Spectroscopy and Near-Infrared Spectroscopy, offer soil-carbon analysis; however, these also are invasive and destructive techniques. The INS approach permits quantification in a relatively large volume of soil without disrupting the measurement site. The technique is very fast and provides nearly instantaneous results thereby reducing the cost, and speeding up the rate of analysis. It also has the potential to cover large areas in a mobile scanning mode. These capabilities will significantly advance the tracking carbon sequestration and offer a tool for research in agronomy, forestry, soil ecology and biogeochemistry.

INS is based on the capture of a fast, 14 MeV, neutron by a carbon nucleus and the subsequent prompt decay, in about 10^{-15}s, of the excited carbon nucleus to its ground state by emitting a neutron and a 4.44 MeV gamma ray. NaI detectors provide quantitative information on the carbon concentration in the material sampled by recording the 4.4 MeV gamma rays.

Our earlier experience at BNL in assessing carbon in humans indicated that INS was a likely candidate for quantifying soil carbon. We demonstrated proof-of-principle of the INS method using our clinical facility. A prototype of a field-deployable INS system was constructed, calibrated for signal yield versus carbon concentration (gC/cc), and tested in double-blind studies against chemical analysis of core samples taken from three different field sites. Table 1 summarizes the agreement between carbon determinations by these two methods. Preliminary results from basic simulations of neutron transport in soil using the Monte Carlo Neutron Photon

(MCNP) code elucidated the details of the processes involved and assisted in optimizing the system.

The proposed INS system is field deployable, directly measures the carbon compartment in soil, and allows multiple analyses of sub-plots at a particular location. A very important feature, however, is that since it does not physically disturb the plot sequential field measurements in a static mode can be maid there. Significant further developments in the proposed technology are possible. For example, by mounting the INS system on a mobile carriage and using in a dynamic mode, large areas could be scanned to provide the true mean carbon concentration in the field as might be needed in forestry, agriculture, and for monitoring carbon-sequestration claims for eligibility for carbon credits. Furthermore, the INS instrument could be modified to allow non-destructive determination of a soil's carbon depth profile or its three dimensional distribution.

An alpha prototype of the INS system became operational in 2003. We present here path forward that identifies the steps required to establish a beta testing site for finally evaluating the viability of INS for field measurements. However, there is an urgent need to establish a soil laboratory for further developmental work. This report recommends continuing the project to bring the INS approach to a fully operational state.

Table 1-1. Comparison of the soil analysis results using INS with the results from chemical analysis, with INS values determined at several sites located at Brookhaven National Laboratory, Long Island. Five core samples were taken from those plots for traditional chemical analysis at the National Soil Dynamics Laboratory, Auburn, Alabama.

	INS gC/cc	**Chemical Analysis gC/cc**
Pine Stand (w/o,l)	0.079 ± 0.005	0.073 ± 0.021
Oak Forest (w/o,l)	0.072 ± 0.004	0.085 ± 0.017
Sand Patch	0.026 ± 0.003	0.025 ± 0.002
Sandy Soil	0.091 ± 0.007	0.104 ± 0.019
Sand Pit (Cal.)	0.0	0.0004 ± ----

(w/o,l) – without leaves, (Cal.) – Calibration site.

2. BACKGROUND

2.1 RATIONALE FOR INS DEVELOPMENT

There is growing concern that increased levels of atmospheric carbon dioxide (CO_2), due to anthropogenic activities, are changing the earth's climate and altering ecological balances through physiological effects on vegetation (Antle et al., 2001; Sarmiento et al., 1999). Understanding of the carbon cycle advanced enormously in the last decade (sources and sinks) and the importance of the terrestrial biosphere as a carbon sink emerged. From 1990 to 1999, the average rate of carbon sequestration from the atmosphere into terrestrial ecosystems was 1.4 ± 0.7 PgC/yr, equal to 22% of anthropogenic emissions of carbon to the atmosphere (Prentice et al., 2001; Houghton et al., 1999). This knowledge opened the prospect of intentionally managing the rates of terrestrial carbon sequestration over the next few decades to increase the amount of carbon stored in vegetation and soils. Although this way may not be considered to be "permanent" storage, such a temporary increase in the rate of carbon sequestration might give us the time needed to change our industrial infrastructure so as to reduce the rate of carbon emission by the middle of the current century. Thus, a precise understanding of carbon balance and dynamics in soil can contribute greatly to developing new strategies to control the near-term rate of increase of atmospheric CO_2.

Soil carbon is derived from the carbon content of plant roots, un-decomposed organic matter on the soil surface, humus in the mineral soil, and, in some cases, deposits of soil carbonate. These pools of carbon are several times larger than the pool in terrestrial vegetation (Schlesinger, 1977; Batjes, 1996), and may change as a result of human activities and global climate change. An inventory of the carbon content of soils is an essential component of any attempt to estimate the source or sink of carbon in the terrestrial biosphere over years to decades.

Much research has focused on the role of soils and soil organic matter in the global carbon cycle. Schlesinger notes that the role of inorganic carbon is poorly known (Schlesinger; 1985; 1992; 1997), and the many gaps in fundamental knowledge (Carbon Sequestration Road Map, 1998, Rosenberg et al., 1999) highlight the need to improve our understanding of soil carbon processes, sequestration, and stability. More accurate baseline inventories are needed over large areas of the stocks of organic and inorganic soil carbon to verify the analytical models and predictions of future carbon sequestration rates and magnitudes. However, current baseline inventories may vary greatly due to large errors associated with field sampling. Such errors in sampling to quantify current estimates of soil carbon and its turnover time are so large that it is very difficult to detect annual changes of even 10% in carbon pools at a particular site. This largely reflects the considerable point-to-point variability in the concentration of organic carbon in soils. Excavating soil, or taking cores destroys the local sample site and samples cannot be taken again in exactly the same spot. The high point-to-point variability would require a very large number (hundreds) of samples within the sample zone of few acres to detect, say, a 1% difference in soil carbon over any period.

2.2 SIGNIFICANCE

New means of carbon detection in soil that are sensitive to small changes over time, or that reduce effort and cost, will improve our understanding of the belowground carbon sequestration

processes, and will assist in confirming existing models and/or derivation of new models of carbon distributions and sequestration. New detection technology will enhance considerably the experimental capabilities at various research sites, such as BER-FACE and AmeriFlux sites, and will contribute directly to Department of Energy's (DOE's) Terrestrial Carbon Processes (TCP) Program and thus contribute to the U.S. Global Change Research Program (USGCRP) and the Carbon Cycle Science Program. This project supports the DOE's mission to protect the Living Planet.

The long-term relevance of this project is based upon the central role that soils play in the global carbon cycle. Long-range interests that would benefit from the availability of a method to measure carbon in soil include, but are not limited to, (1) directly measuring total and inorganic carbon and other elements in soil; (2) monitoring soil carbon levels and rates of change resulting from alternative land use and management strategies; (3) monitoring the efficacy of new carbon-sequestration methods; (4) developing an international procedure for monitoring carbon sequestration in soil for verifying the assessments of the International Panel on Climate Changes (IPCC) that, under the current version of the Kyoto Protocol, would credit nations demonstrating net carbon sequestration; and, 5) contributing to understanding of the belowground processes and responses of forests and other vegetation to future atmospheric CO_2 enrichment, as evaluated in the DOE-sponsored FACE research projects. Although soils are not explicitly considered in the current Protocol, the potential for net carbon sequestration in soils has received careful attention by the IPCC group examining Land Use, Land Cover and Forestry.

Carbon dioxide-induced shifts in carbon partitioning by plants might influence the soil's carbon dynamics. Both the quantity and composition of plant residue are important to the soils' carbon stocks and to maintaining its quality (Pieri 1995) including water holding capacity (Hudson 1994) and nutrient cycling. Polglase et al., (1992) assessed the potential of CO_2 to enhance carbon storage in land systems and reported characteristic residence times for carbon in leaves, branches, stems, and roots; their differences indicate the impact of the biosphere on soil carbon dynamics. Schlesinger (1991; 1993) assessed terrestrial response to global change with a brief discussion of carbon storage (and residue management) in agricultural ecosystems. "Successful management of agricultural soils may depend upon the preservation of their organic micro-aggregate structure", and "Knowledge of carbon dynamics is the key to wise soil management that will sustain our fertile agricultural lands and keep them plentiful as we seek to maintain a research base that can assure world food security."

The INS system will be a major breakthrough in quantifying soil carbon that would be much welcomed especially in the context of the global carbon problem. In addition, the method will find applications for quantification of crop residue management, soil carbon cycling, and soil dynamics and quality. Rapid, accurate, low-cost, and non-invasive methods to measure and monitor changes in soil carbon content over large areas are integral to including changes in soil carbon inventories as credits (or debits) under the Kyoto Protocol.

2.3 Objectives

This multi-disciplinary project involves the expertise of nuclear physicists (L. Wielopolski, S. Mitra, and I. Orion), an ecologist (G. Hendrey), plant physiologists (H. Rogers, and S. Prior), soil scientist (A. Torbert), and soil microbiologist (B Runion). Specifically, the issues discussed above can be related to (a) the ecology and community dynamics of belowground biota and their

interactions within the soil; (b) the feedback from soils, sediments, and associated biota to atmospheric composition and climate; (c) the coupling of processes in soils; (d) the development of approaches to relate static soil characteristics to its properties and fluxes to and from the soil, (e) the closure of the carbon budget within a forest stand (e.g., FACE and AmeriFlux). These issues can be addressed in part by the proposed Inelastic Neutron Scattering (INS)-induced gamma ray spectroscopy system through its unique ability to non-destructively measure carbon and other elements in a large volume of soil *in situ*.

The short-term objective of the proposed research were to construct a prototype INS system to non-destructively measure soil carbon in the field, to calibrate the system, and verify it in the field in collaboration with soil- and plant- scientists. The long-term objective is to develop a reliable, well-characterized, portable system to non-destructively measure the content of carbon *in situ* for many types of soil. A system well characterized for various soil types will enable determinations of the temporal changes in soil carbon without perturbing the measurement site, i.e., with the INS system soil carbon can be quantified in the same plot, in the same volume of the soil, again and again, over years, avoiding problems of point-to-point heterogeneity. The system can be designed for static measurements, in a single spot, or for scanning large areas. The precision of the measurement is related to the length of time the INS measurement is made at a particular site. Consequently, in static mode, it should resolve changes in carbon content of less than a percent. It is envisioned that following site characterization, multiple sites can be measured in a single day with the analytical results following immediately thereafter.

2.4 Need for New Methods

At present, carbon in soil is assessed indirectly, using analytical models, and directly by taking core samples to the laboratory. The latter is plagued by both the extreme spatial variability of carbon in soils and by the intensive labor requirements for sampling and separating various components, and finally analyzing them for carbon content. Standard methods for measuring soil properties, including carbon, are extensively documented (Carter 1993; Culley 1993; Page et al. 1982; Klute 1986; Maqgdoff et al. 1996; USDA-NRCS, 1996; and Taylor et al. 1991). However, there are onbly few reports on *in situ* direct noninvasive measurements of carbon in soil.

Using the INS in the continuous scanning mode would improve the database for carbon content over large areas that would be appropriate for scaling-up for global and regional models, and supersede the resent practice of extrapolating carbon point measurements to larger areas. Scans over many hectares, if need be, would give a true mean value of the carbon content. Furthermore, such non-destructive soil analysis *in-situ* would allow true sequential measurements to evaluate changes over time due to changes in land-use practices.

2.5 New Methods

The specific gap that this project proposes to bridge is to provide a direct, non-destructive measurement of soil carbon *in situ*. Several methods recently were suggested. One method uses mid- and near-infrared diffuse reflectance spectroscopy (IRDRS) (McCarty et al. 2002). A second employs laser-induced breakdown spectroscopy (LIBS) (Cramers et.al., 2001; Kincade, 2003; Mouget et al., 2003; and Ebinger et.al., 2003). However, neither of them is truly noninvasive or non-destructive. In the IRDRS approach, a probe is mounted on the edge of a shank that is

adjusted to a depth of five or ten centimeters into the soil and dragged throughout the field. The probe samples the soil to a depth of few millimeters from the tip of the shank. LIBS insert a probe into the soil to vaporize a small sample (about 50 micro-liter), and provide a very small point measurement, that point is destroyed in the process. A modified application of LIBS is to obtain point sample from the interior of a soil core. In either case, only discrete small points are analyzed and the assumption made that these represent a homogeneous, three-dimensional core. Daniels (1966) proposed using ground-penetrating radar (GPR) to assess the volume of the roots and from this to imply on carbon changes in soil. This also is an indirect method in which the root mass is obtained from the reconstructed 3-D images of the root system. Knowing the root mass, and with assumptions about the carbon content of roots, at best the carbon in the root system can be calculated. Although viability of this approach was demonstrated, its drawback is the lack of sensitivity for small roots, below two to three millimeters (Wielopolski and Hendrey, 2000). However, a mature GPR 3-D reconstruction system that could give root volume would be a powerful tool when coupled with knowledge of the total carbon content in the soil. The INS method to measure carbon in soil non-destructively described in this report is a nuclear method based on spectroscopy of gamma radiation induced by inelastic neutron scattering from carbon and other element nuclei. It provides elemental information and is insensitive to the soil chemistry..

3. INS METHOD

3.1 THEORY

Using fast neutrons for non-invasive bulk soil analysis *in situ* enables depth, about 25 cm, penetration into the soil and induces specific elemental signal from carbon and other elements. These neutrons might be elastically scattered from various nuclei present in the soil, thereby losing kinetic energy down to a level at which they will be absorbed and induce prompt gamma emission or delayed activation (Alfassi et al., 1995; Nargolwalla et al., 1973). However, some of the neutrons, before reaching thermal energies (energy that is in equilibrium with the thermal motion of the surrounding matter at about 25 meV), will undergo absorption raising the nucleus to one of its excitation levels. This energy will subsequently decay to a ground state via simultaneous emission of a particle and one or more gamma rays. When the emitted particle is a neutron, the reaction is referred to as an inelastic neutron scattering (INS) and it is characterized by the threshold energy for this reaction, meaning that it does not occur below that energy. Absorption of a neutron by a nucleus with charge z and mass n+z transforms it to an isotope with mass n+z+1 in an excited state, schematically depicted in Fig. 1, where the asterisk denotes such a nucleus. Selections of the various neutron processes are governed by the neutron cross-sections (probabilities) that are known for every element; for example, the inelastic neutron scattering cross-section for carbon is shown in Fig. 2. The unit of cross-section is a barn that equals to 10^{-24} cm^2 (Majuro et al., 1982).

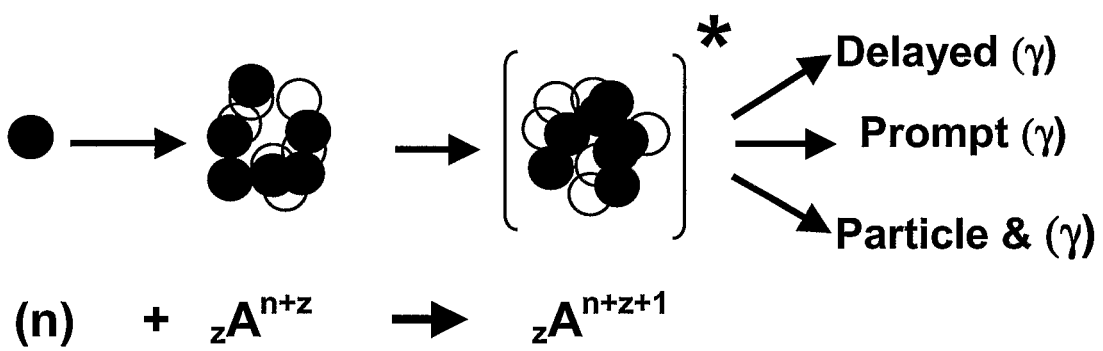


Figure 1. Outline of a neutron-absorption process.

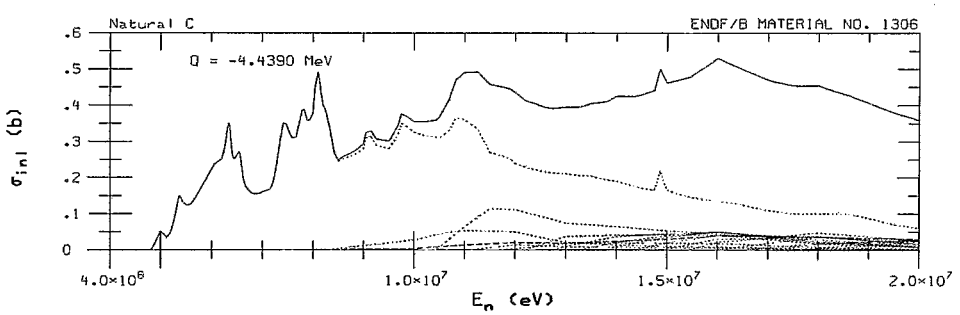


Figure 2. Total inelastic neutron cross-section,

An electrical device such as a neutron generator that operates similarly to those devices generating x-rays produces the fast neutrons required for the INS interactions. After absorbing the fast neutron the excited carbon nucleus decays to the ground state by emitting 4.44 MeV gamma radiation that is counted with NaI scintillating detectors (Knoll 1979). The area under the 4.44 MeV carbon peak is proportional to the carbon concentration in the soil. The response of these detectors was compared with those from Bismuth Germanate (BGO) using Monte Carlo calculations (Orion et al., 2000). Thus, the prompt inelastic scattering reactions (n,n'g) produce gamma rays when a neutron is scattered by a target nucleus that are emitted without delay. The gamma ray energy is characteristic of the scattering nucleus. These reactions are particularly useful for detecting C, N, O, Mg, Al, Si, S, and Ca.

3.2 INSTRUMENTATION

The INS system consists of a neutron generator for producing fast neutrons, nuclear detectors for detecting the gamma signal from carbon nuclei, nuclear spectroscopy electronics for signal processing, and finally, a data acquisition system that stores the acquired signals in the form of a spectrum.

3.2.1 Neutron Generator:

The basic operation of a fast 14 MeV neutron production is based on a deuterium-tritium fusion reaction ($d + t \Rightarrow \alpha + n$) that emits neutrons isotropically. The fusion reaction takes place in a sealed neutron tube consisting of an ion source, focusing electrodes, acceleration electrodes and a target composed of zirconium impregnated with tritium. The target is a thin film of a metal such as titanium, scandium, or zirconium, which is deposited on a copper or molybdenum substrate. Titanium, scandium, and zirconium combine with hydrogen or its isotopes to form stable chemical compounds called metal hydrides. These hydrides are made up of two hydrogen (deuterium or tritium) atoms per metal atom, endowing the target with to have extremely high densities of hydrogen that is important in maximizing the neutron yield of the neutron tube. Metal hydrides also are the active material of the gas-reservoir element. All neutron tubes are designed such that the gas reservoir element and the target each incorporate equal amounts of deuterium and tritium. In these mixed gas tubes, both the ion beam and target contain 50% deuterium and 50% tritium; accordingly. The tubes have very stable neutron yields over their operational life-time. Deuterium ions are accelerated from a Penning-type ion source to the tritiated anode that is at about -130kV. The ion source operates with crossed electric and magnetic fields that ionize and steer the deuterium gas to the exit. A 3.0 kV DC anode potential with respect to the source cathode generates the electric field, while a cylindrical permanent magnet provides the magnetic field. A reservoir element supplies deuterium gas for operating the ion source and controlling the gas pressure inside the tube. Electrical heating or cooling of the reservoir filament controls the gas pressure. The element is initially loaded with an amount of deuterium equal to the amount of tritium (~2Ci) contained in the target. Figure 3 is a schematic of a neutron generating tube, and Figure 4 is an actual picture of one.

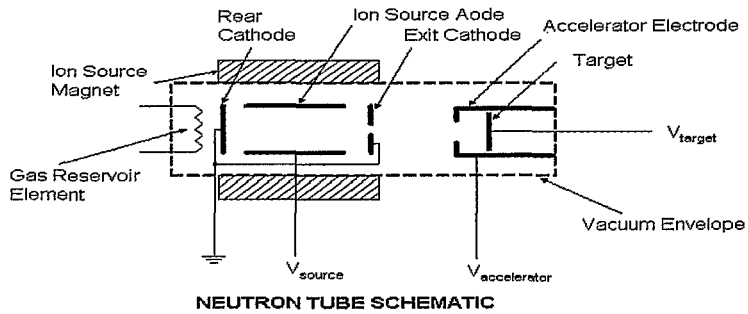
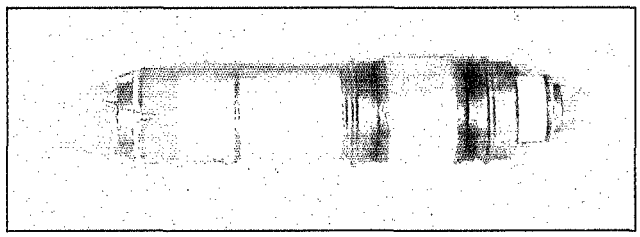


Figure 3. Schematic of a neutron tube using Penning-type ion source.

Figure 4. Glass sealed neutron generator tube about 10 cm long and 2.5 cm in diameter.



3.2.2 Nuclear Detector

A conventional NaI scintillator (Fig. 5) was used to detect the characteristic gamma radiation emitted from the soil. Its large volume, 15cm diameter by 15cm high, offers high detection efficiency with reasonable energy resolution to separate gamma rays with various energies interacting within it. A more efficient BGO scintillator also was evaluated; however, its energy resolution is lower and its temperature coefficient is much lower, thus complicating its outdoor use.

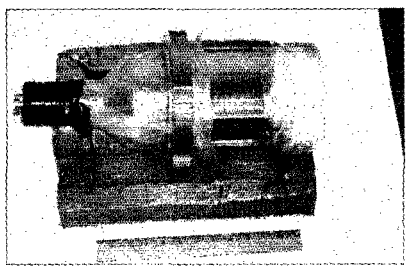


Figure 5. NaI detector 15 cm x 15 cm

3.2.3 Nuclear electronics:

The experiments started with an analog system (Fig. 6a) that subsequently was replaced with digital electronics (Fig. 6b). The analog system consisted of off-the-shelf units that comprise conventional nuclear gamma-ray spectroscopy electronics. On one end it is connected to the detector and on the other end to an analog digital converter (ADC) and a multi-channel analyzer (MCA) data-acquisition system. The digital system digitizes the signal immediately after the pre-amplifier, thus eliminating the need for amplifier and the ADC makes the digital signal analyzer (DSA) system much more compact. Moreover, with the DSA box there is no need for a power supply for the detector. The count-rate capabilities of the DSA systems are superior to those of the analog systems.

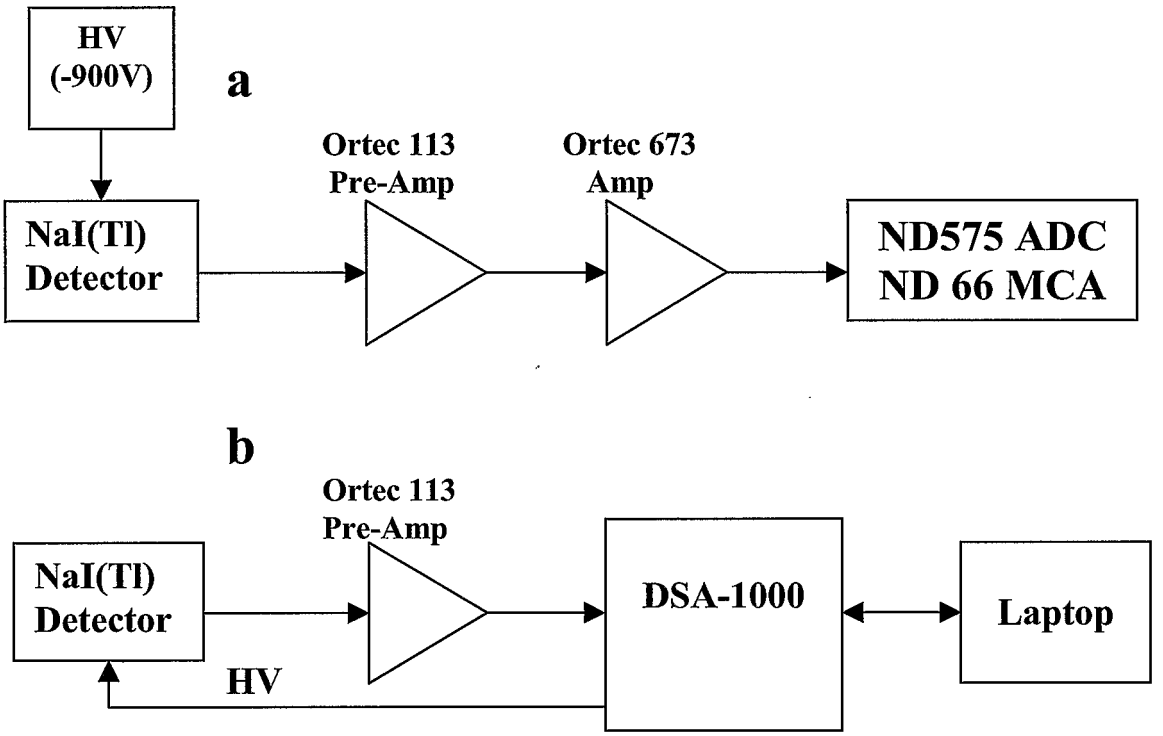


Figure 6. Block diagrams of the analog (a) and the digital (b) data acquisition systems used in the current experiments.

3.2.4 Data acquisition:

The data-acquisition systems analyze the height of the incoming pulses and store them, sorted according to their amplitudes, as a histogram (also called a spectrum). Traditionally, all these functions were performed in a multi-channel analyzer (MCA). In digital systems, since the signal is digitized immediately after the preamplifier, all subsequent functions are performed by software in a digital signal analyzer (DSA) system. A similar pulse-height spectrum is delivered to a external computer for display. Thus DSA systems are much more compact and faster with higher capabilities of signal processing thereby improving the overall signal throughput.

3.3 EXPERIMENTAL SET-UPS

Several experimental set-ups were evaluated for measuring soil carbon. The initial feasibility studies employed an existing clinical set-up for measuring total carbon in humans. In this configuration, the 35 kg soil sample was irradiated by the source beneath it, with the detector placed 90 degrees to the source-sample axis. The results demonstrated the viability of the INS approach for detecting carbon in soil (Wielopolski and Orion, 2000).The general INS set-up used in subsequent carbon analysis in soil *in situ* is one in which the neutron generator and the detection system were placed on the same side on top of the soil's surface, Fig. 7. This arrangement necessitated optimizing the shielding materials used in the mixed gamma-neutron fields and the spacing between the NG and the detection system. These two factors controlled the background count rate that affected the signal-to-noise ratio (SNR). Furthermore, high-count rates generate non-linear effects, such as pulse pile-up, that causes spectral distortions and losses

of counts in the photopeaks. To improve the SNR, the NG was operated in a pulsed mode and separate gamma-ray spectra were acquired during and after the neutron pulse; the pulsing strategy is shown in Fig. 8. The optimized MCA gate signal is shown in Fig. 9.

Table 3-1 summarizes the optimal operating parameters of the NG following the considerations outlined. These parameters were maintained throughout the subsequent experiments.

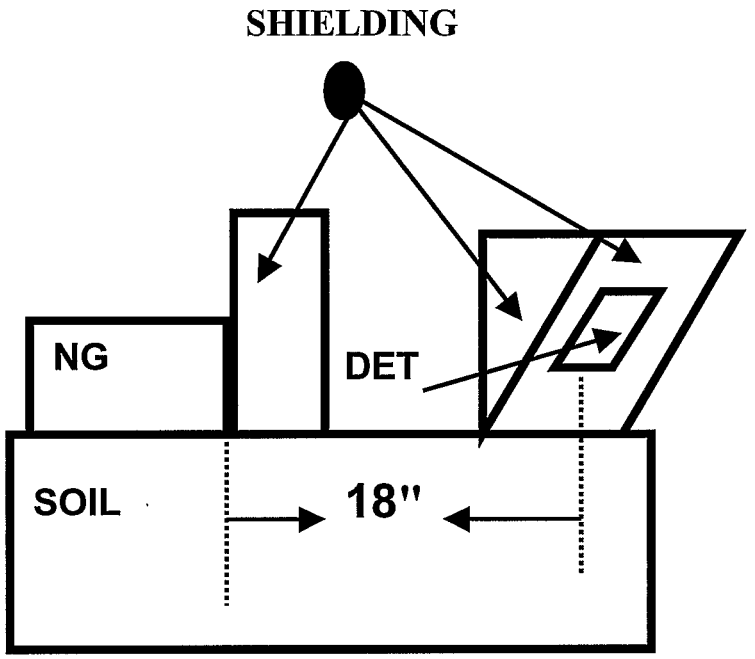


Figure 7. Layout of the INS system indicating the relative location of the main components.

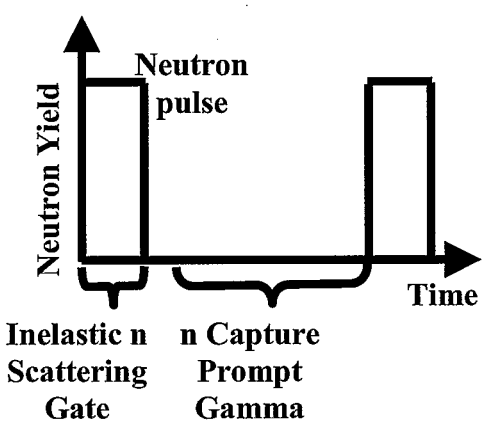


Figure 8. Schematic presentation of a NG pulsing controlled by the NG trigger. Fast neutrons are produced only during the trigger pulse.

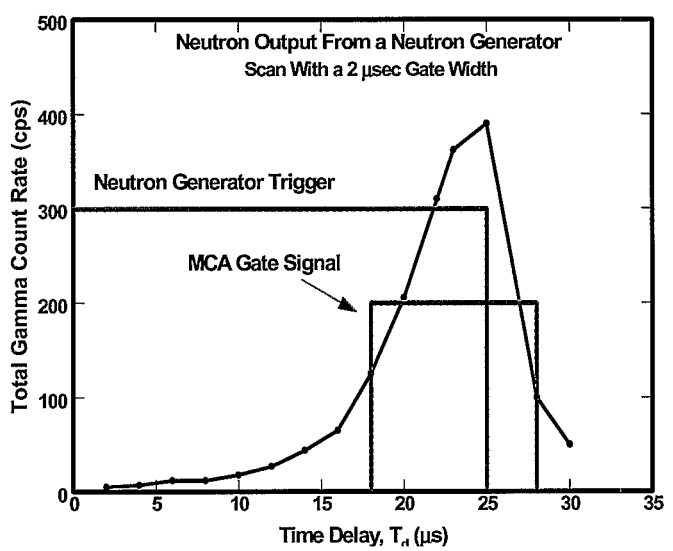


Figure 9. Actual yield of neutrons yield (black line) relative to the NG trigger and the optimized MCA gate signal.

Table 3-1. Operating parameters for the neutron generator.

High Voltage	**80 kV**	**Duty Cycle**	**25%**
Beam Current	**50 μA**	**MCA Gate Delay**	**18 mms**
Frequency	**10 kHz**	**MCA Gate Width**	**10 mms**
Running Time	**1800 s**	**Detector on the NG main axis**	

The output of the neutron generator is continually monitored using a plastic scintillator sensitive to neutrons. Thus, all experimental results are normalized to the same number of neutrons.

The INS technique is referred to as an on-line method in which the sample is irradiated and data are acquired simultaneously. Consequently, the detection system is exposed to a mixed gamma-neutron radiation field that tends to reduce the SNR. To reduce the background radiation, the neutron generator and the detector were surrounded with shielding materials. In the initial set-up, in a former hot cell, the INS system was placed on top of a large aluminum box 152x122x122 centimeters filled with sand 91 cm high to simulate field conditions. However, the high neutron albedo from the cell walls and the room's gamma background proved too excessive to be reduced with a reasonable amount of shielding; about 900 kg was required (Fig.10). Since the prime interest is to measure carbon, all carbon-shielding materials were avoided. Accordingly, the innermost layer immediately surrounding the NG on the sides and on the top was composed of iron bars 15 cm thick, followed by 22.5 cm thick layer of borated water containing 4.9 % boron by weight.

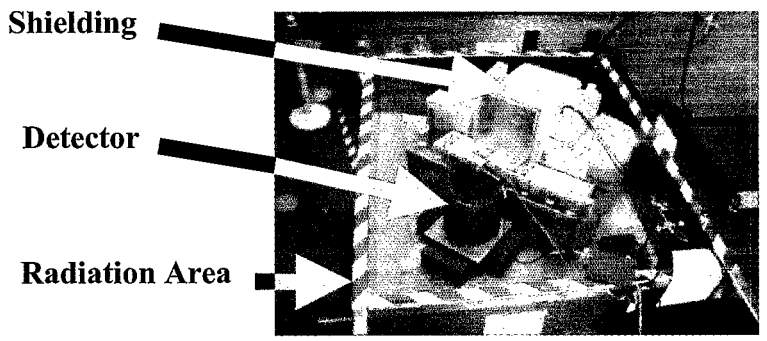


Figure 10. Shielding required reducing the count rate in the detector in the hot cell.

For more realistic experimental conditions, the INS system was moved from the hot cell and put on the ground in an outdoor tent. The shielding surrounding the NG was entirely removed and only a shadow shielding was interposed between the NG and the detector (Fig. 7).

3.4 SPECTRAL ANALYSIS

The measured spectra were analyzed using the Trapezoidal Method (TM). In this method, the background (B) under the peak of interest is assumed to be linear and can be approximated by a trapezoid whose bases are the number of counts on each side of the peak selected by a region of interest (ROI). Thus, the net number of counts (N) is expressed as the difference between the total number of counts (T) in a selected ROI minus background

$$N = T - B \tag{1}$$

and the error σ_N in the net counts is given by

$$\sigma_N = \mathrm{sqrt}(T + B) \tag{2}$$

Further assumptions inherent in the TM method are that within a ROI the analyzed peak is a single one, i.e., it is not a doublet or a triplet that cannot be resolved, and that the background is relatively smooth without sharp changes within the ROI. All the peaks present in the spectrum are analyzed using this method. There are better methods for spectral analysis, such as the Library Least Squares (LLS) method, that can resolve doublets and minimize error propagation; however, a major effort is required to prepare library standards these would be developed once the system is finalized (Wielopolski 1981; Wielopolski et al. 1984).

3.5 CALIBRATION

After determining the carbon line intensity, areas under the peak, the net counts are calibrated against known carbon concentration in soil, thus converting the area into mgC/cc. The calibration was obtained by mixing sand with 0, 2.5, 5.0, and 10.0 % carbon by weight. These calibration mixtures, about 1590 kg each, were placed in a 152x122 cm x 45 cm deep pit. For that purpose, clean dry construction-grade sand, confirmed as containing no carbon, was mixed with 8-12 mesh size activated charcoal (amorphous carbon) that is almost 100% carbon The standards were prepared manually by homogeneously distributing the charcoal throughout the sand. Each standard was measured four times for 1800 s and the mean values were used for calibration. Taking a sample and determining the weight and volume yielded the bulk density for every standard. The bulk densities varied from 1.56 g/cc for sand alone to about 1.42 g/cc for sand mixed with 10% carbon. Since the INS instrument sees constant volume, each calibration point was converted from carbon percent fraction to carbon density using the measured bulk densities. Figure 11 shows the calibration line for carbon thus derived. The high intercept on the y-axis is the result of 4.44 MeV gamma rays cascading from the 6.27 MeV excited state of silicon through the 1.78 level to the ground state. However, this interference is easily accounted for by using the 1.78 MeV gamma line emitted coincidentally with the interfering line whose ratio is constant. The raw spectral data from the calibration is provided in Appendix A.

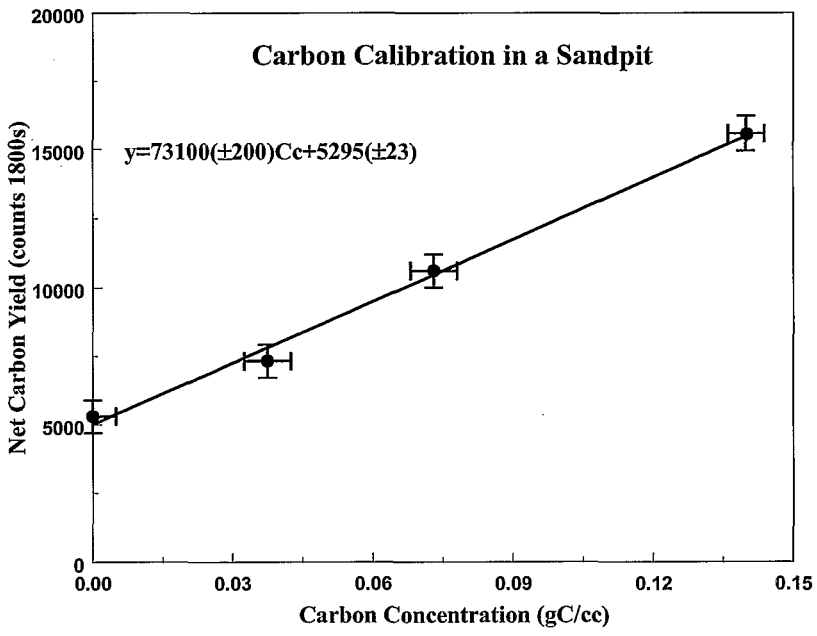


Figure 11. Calibration carbon yield versus carbon

3.6 SAMPLED VOLUME

One characteristic of the INS system is that it samples a constant volume, i.e., a volume resulting from the intercept of the neutron field in the soil and the solid angle subtended by the

detection system. Consequently, the detected signal is proportional to the number of atoms encountered in the common volume or to the elemental concentration in g/cc. However, to assess the total carbon stock the sampled volume must be determined or the system calibrated in grams of the total amounts of the element of interest. This is possible because all samples of interest are semi-infinite with saturation thickness. An initial estimate of the sampled volume is assumed to be that at which neutron flux is attenuated to about 0.5%, which corresponds in Figs. 20 and 21 to a depth of about 18 cm. Thus, considering a hemisphere with 18 cm radius, the volume is about 0.01 m^3. Since the response is not uniform throughout the volume and depends on the number and placement of the detectors, more thorough calculations and measurements are required.

4. RESULTS

The INS system calibration was verified in a double-blind studying in which the INS and the chemical analysis were performed by two different teams and the results were compared by a third party. These comparisons were carried out in three different field sites located at BNL; a pine stand, a sand patch within a grassy field, and an oak forest. Subsequently five-core-samples, each two inches in diameter were taken from each site for independent chemical analysis.

4.1 INS MEASUREMENTS

The test sites included, first, a small, undisturbed pine stand where two measurements were taken straight on the needle bed, and then from the soil after removing manually the needle litter. The second site was a sand patch with landfill debris and the third site was an oak forest where before measurement the coarse forest litter was removed. Two spectra were acquired at each site; one inelastic spectrum in coincidence with the neutron pulse and the second prompt gamma spectrum in anticoincidence with the neutron pulse. Each spectrum was acquired for 1800 s. Figure 12 shows these three sites. Soil cores also were taken from each site for chemical analysis as described later.

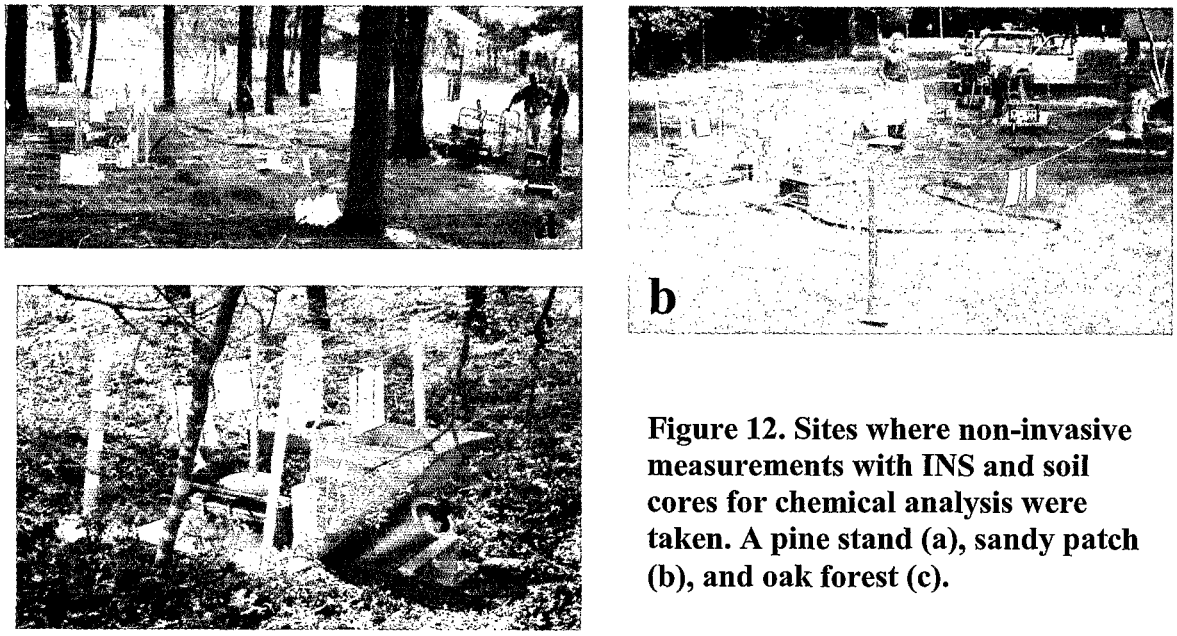


Figure 12. Sites where non-invasive measurements with INS and soil cores for chemical analysis were taken. A pine stand (a), sandy patch (b), and oak forest (c).

Appendix B summarizes the raw data from these measurements. Two typical spectra; one from inelastic neutron scattering acquired during the neutron pulse and one due to prompt gamma resulting from neutron capture in the soil are shown in Fig. 13.

The spectra from forest measurements are given in Appendix C. The results clearly demonstrate the instrument's capability for measuring normal carbon levels in these three sites. The error in the measured carbon is about 5%; the low level of carbon in the sandy patch has an error of about 12%. Increasing the number of detectors, prolonging the counting time, and further optimization of the system's configuration can reduce these errors. Similarly, incorporating such improvements will heighten the sensitivity of the system and reduce the minimum detection limit (MDL), defined as three times the square root of the background under

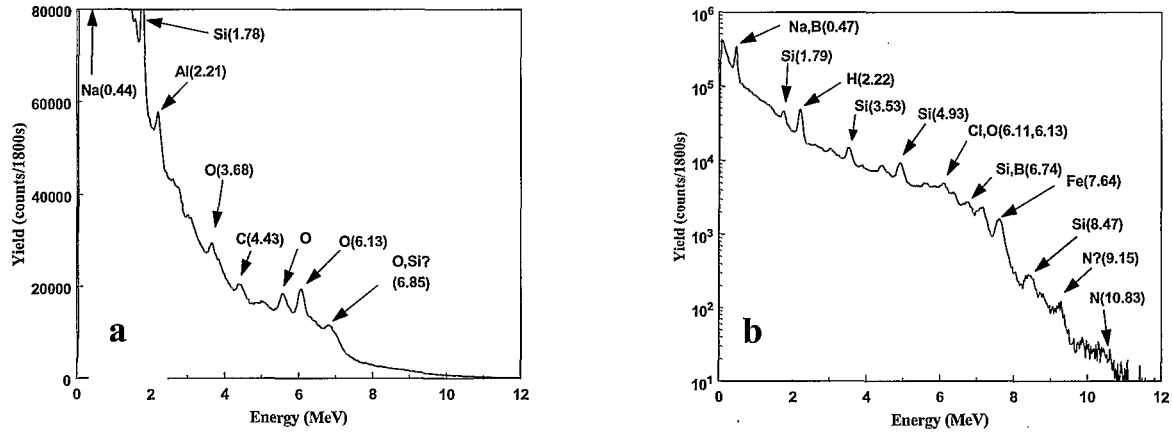


Figure 13. Typical "Inelastic" (a) and "Prompt" (b) gamma spectra from a pine stand.

the peak. At present, the MDL is about 0.018 gC/cc, or assuming a soil bulk density of 1.5 g/cc, about 1.2% C by weight. The standard error in the measured carbon values is about 5%. Although the litter on top of the soil in the pine stand was not included in the chemical analysis, the carbon content in the INS measurements with and without the litter is significantly different, indicating the sensitivity of the method to the carbon encountered in the litter. The carbon analyses are summarized in Table 4-1.

Table 4-1. Carbon analysis from spectra acquired during 1800 sec counting time

	C_N	gC/cc
Pine Stand (w,l)	**12512 ± 696**	**0.099 ± 0.005**
Pine Stand (w/o,l)	**11080 ± 696**	**0.079 ± 0.005**
Oak Forest (w/o,l)	**10588 ± 655**	**0.072 ± 0.004**
Sand Patch	**5017* ± 506**	**0.026 ± 0.005**
Sandy Soil	**8071* ± 492**	**0.091 ± 0.002**
Sand Pit (Calib)	**5035 ± 607**	**0.0**

***Si corrected**

In this table C_N is the normalized net number of counts in the carbon photopeak; the normalization was performed to the same number of neutrons counted with a plastic scintillator. The parenthesis denote (w,l) with litter and (w/o,l) without litter. The third column is the carbon concentration using the calibration line shown in Fig. 11. The remaining peaks were also analyzed and are summarized in Appendix D. The silicon correction consisted of normalizing the net carbon counts to the same number of counts in the silicon peak obtained during the calibration in the sandpit.

4.2 Chemical Analysis

Following the INS measurements, one core sample (5 cm in diameter and 40 cm long) was taken from each corner of a plot 0.09 m^2 (30 square cm), and from the center of the square where the INS measurement took place (total of five) (see Fig. 14). The National Soil Dynamics

Laboratory, Auburn, Alabama, analyzed these samples. The results of the INS measurements and of the chemical analyses were withheld from the respective teams until all analyses were completed.

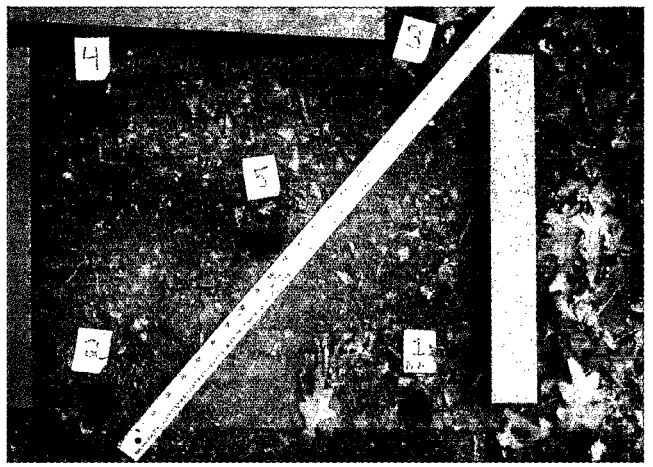


Figure 14. Location of the five soil cores taken from each site. The center core corresponds to the center of the INS measurement.

The core samples were partitioned into 0-5, 5-10, 10-20, 20-30, and 30-40 cm subsamples. Two aliquots, two grams each, from each subsample were measured for water content and bulk density using standard analytic techniques (Dane and Topp, 2002). A total of 150 (3x5x5x2) subsamples of soil were dried (55°C), ground to pass a 0.15-mm sieve, and analyzed for total carbon and total nitrogen on a LECO CN 2000 (LECO Corp., Saint Joseph, MI). In addition the depth of the organic horizon was determined. Appendix F contains all the results of the soil core analysis.

Figure 15 shows the large variability in the bulk soil density with depth in the pine stand and in the oak forest. Such large variations in the bulk density affect the distribution of other parameters that depend on it. In Fig. 16, the density distribution in the five cores taken from the oak forest shows the systematic variation of the density versus depth. For example, the carbon distribution expressed as %C differs significantly from that when expressed as carbon

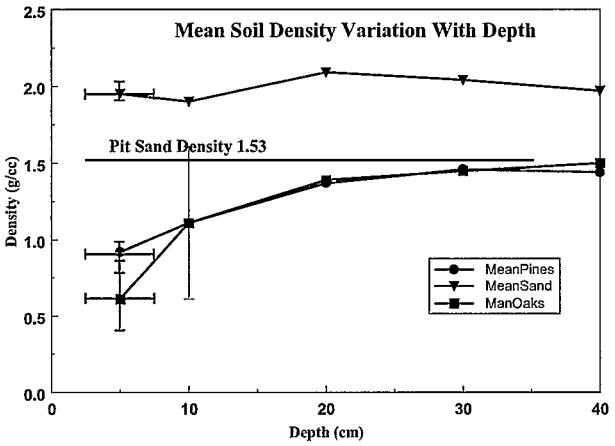


Figure 15. Variation of soil bulk density versus depth at three sampled sites and in the sandpit.

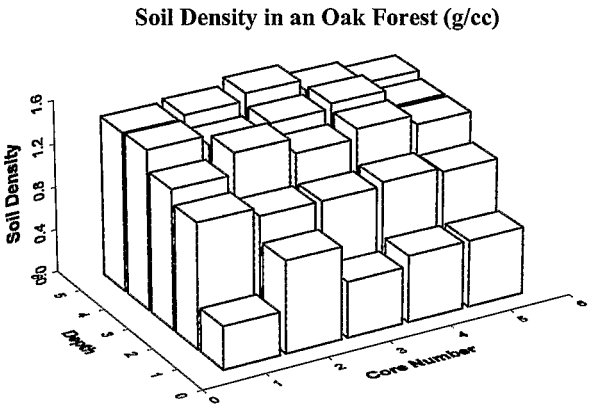


Figure 16. Soil bulk density in the five cores taken from the oak forest.

concentration in mgC/cc; Fig. 17 shows these two distributions.

4.3 COMPARISON

To correctly compare the INS measurements and chemical analyses, proper calibration must be used. We pointed out that the INS system sees constant volume; therefore, the intensity of the

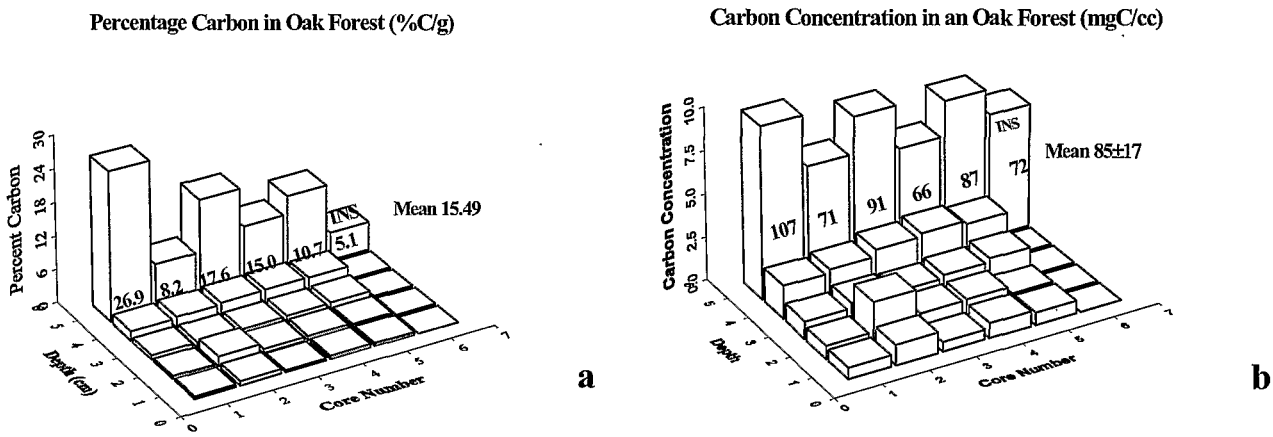


Figure 17. Percent carbon (a) and carbon concentration (b) distribution in the oak forest.

observed signal is proportional to the number of carbon atoms in that volume. Since the volume is constant, the measured carbon signal is proportional to carbon density. This is apparent in Fig. 17 where the bar graph of percent carbon distribution in
the oak forest varies considerably and the mean value of 15.49% is basically in disagreement with the INS value of 5.1%, Fig.17a. However, when the values are converted to carbon concentration using measured density values, the mean value of 72 mgC/cc agrees well with the INS measurement of 72 mgC/cc, Fig. 17b. The same relationships were observed in all the other sites. Table 4-2 and Fig. 18 summarize the final comparisons of the INS measurement versus chemical analysis.

Table 4-2. Comparison between INS and chemical analysis of soil analysis.

Site	INS (gC/cc)	Chemical Analysis (gC/cc)
Pine Stand (w,l)	0.099 ± 0.005	---
Pine Stand (w/on,l)	0.079 ± 0.005	0.073 ± 0.021
Oak Forest (w/o,l)	0.072 ± 0.004	0.085 ± 0.017
Sandy Patch	0.026 ± 0.003	0.025 ± 0.002
Sandy Soil	0.091 ± 0.007	0.104 ± 0.019
Sand Pit (Cal.)	0.00	0.0004 ± ---

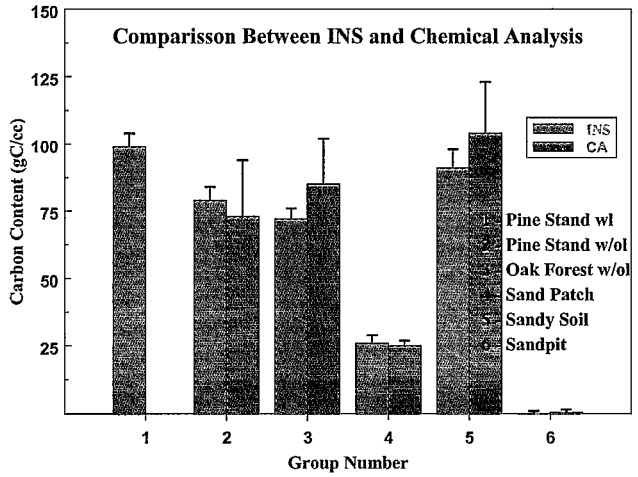


Figure 18. Comparison between INS and chemical analysis of soil samples.

5. MODELING AND SIMULATIONS

5.1 MODELING

An important parameter in the INS measurements is the soil's bulk density because it affects the number of atoms in the volume seen by the detection system. The soil density is required to properly calculate the elemental concentrations and is essential in Monte Carlo simulations. In general, density (or bulk density, D_b) is defined as the total soil's weight per unit total volume. Inherent in this definition is the assumption that the soil's three-phase system is homogeneous, which is reasonable for soil particles that are smaller than the neutron- or gamma rays mean free path. The neutrons' macroscopic cross-sections and gamma mass attenuation coefficients also depend on the soils' bulk density thus affecting the reaction rates and penetration depth of neutrons and gamma radiation. The soils' density depends on its morphology, i.e., particle shape and size distribution, which is characterized through the porosity parameter, P. Porosity is defined as the ratio of the non-solid pore space divided by the total space. The pore space may be partially, P_w, or completely, P_w=1, filled with water so affecting density, where P_w is defined as the water volume in the pore space divided by the total pore volume. If the density of the solid matter is assumed to be D_s and that of the liquid phase D_w, then the soil's bulk density can be expressed as:

$$\mathbf{D_b = D_s (1 - P) + D_w P P_w} \qquad \textbf{(3)}$$

For simplicity, assuming arbitrarily that density for the solid and liquid components is 3 and 1 g/cm^3, respectively, and that values range between 0 and 1 for P_w and P, Eq. 3 is depicted in Fig. 19. However, more realistic values for these parameters are for D_s, 2.4 to 2.7 g/cm^3, D_w slightly above 1 g/cm^3 because of the dissolved minerals, porosity in the range of 25% to 50%, and typical values for D_b in the range of 1.2 to 1.6 g/cm^3 (Frank 1993). In practice, the soils' bulk density is defined on a dry basis, i.e., $P_w = 0.0$.

Figure 19 shows that Eq. 3 does not exhibit sharp gradients in the bulk density in soil. Those can be encountered only at the interfaces between the soil and solid rocks. However, as long as the soils' volume relative to the beam's size remains small, despite substantial changes in density, there will be an averaging effect that will smooth out these sharp discontinuities.

5.2 MCNP SIMULATIONS

To facilitate optimization of the system, and to undertake numerical experiments that otherwise would be difficult, costly, or impossible to perform, probabilistic codes that simulate the whole system are employed. One of them is the Monte Carlo Neutron Photon (MCNP) transport code, developed in Los Alamos National Laboratory (Breismeister, 1993). In addition to knowing the system's configuration, two essential parameters for MCNP calculations are the soil's bulk density and elemental composition. The latter is not always readily available. The criticality of the elemental composition depends on the purpose of the calculations; for example, for soil activation calculations detailed information about composition down to the trace levels is required. On the other hand for transport calculations, a list of the major and minor elements suffices. If there is no information about the particular soil, then a few samples can be taken for elemental analysis. Table 5-1 gives examples of such results; those for Soil A with density of 1.59 g/cm^{-3} were determined from chemical analysis. In this case, there was a need to determine soil activation due to high-energy neutrons, thus trace level elements were included. Soil B in

$$D_b = D_s(1-P) + D_w P P_w$$

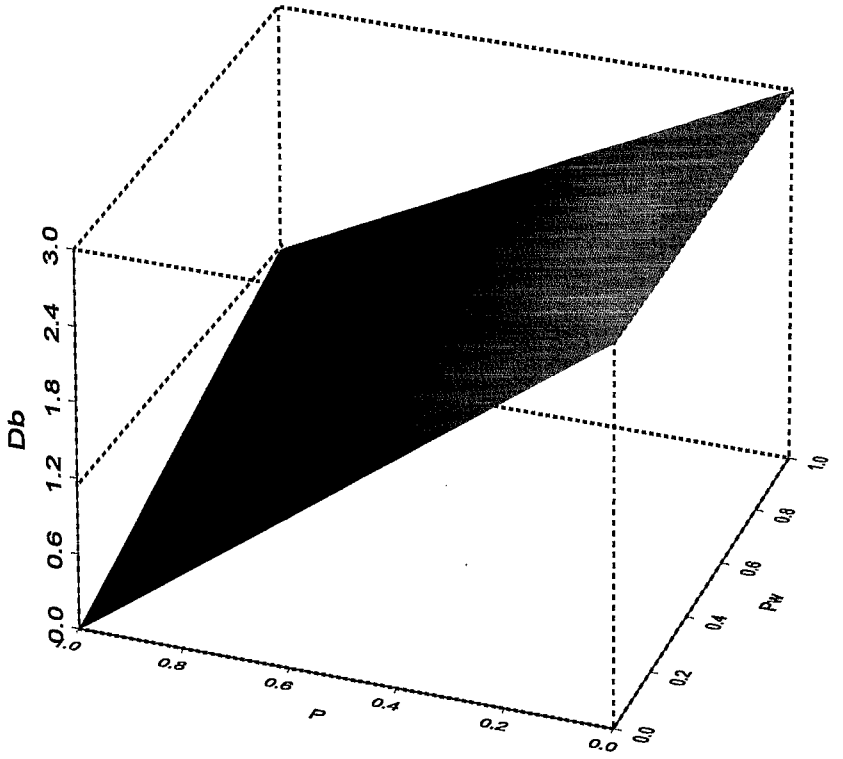


Figure 19. Soil bulk density according to Eq. 3 versus porosity and water fraction.

Table 5-1 represents a carbon-rich loam soil used by the PEGS5 Monte Carlo code for transport calculations in soil (Nelson et al.,1997). Median values of world soils (oven-dried) are given in Table 5-1 under Soil C (Summer, 2000). Since the true distribution of the elements in the soil is seldom known, a uniform distribution is frequently assumed although it is well known that there are sharp gradients in C, N, and D_b from the surface through the first 10 to 15 centimeter of the soil's profile.

Table 5-1. Elemental soil composition for Soil A: Chemical analysis of a local soil at the laboratory, Soil B: Soil composition used in the data set of the PEGS4 code, and Soil C: is the median value of world soils.

Element	Soil A (% by weight)	Soil B (% by weight)	Soil C (% by weight)
^{1}H	0.2100	2.810	---
^{3}Li	0.0013	---	0.0030
^{5}B	0.0013	---	0.0010
^{6}C	0.1950	14.430	2.0000
^{7}N	0.0032	0.001	0.1000
^{8}O	53.0200	49.640	48.8700

^{9}F	0.0046	---	0.0200
^{11}Na	0.2450	0.820	0.6300
^{12}Mg	0.0881	---	0.5000
^{13}Al	1.0960	8.930	7.1000
^{14}Si	43.7600	21.320	33.3000
^{15}P	0.0128	---	0.0650
^{16}Cl	0.0108	---	0.0100
^{19}K	0.2250	0.560	1.4000
^{20}Ca	0.1180	0.540	1.3700
^{21}Sc	0.0005	---	0.0007
^{22}Ti	0.1228	---	0.5000
^{23}V	0.0035	---	0.0100
^{24}Cr	0.0029	---	0.100
^{25}Mn	0.0151	---	0.0850
^{26}Fe	0.7240	0.960	3.8000
^{27}Co	0.0007	---	0.0008
^{28}Ni	0.0009	---	0.0040
^{29}Cu	0.0012	---	0.0020
^{37}Rb	0.0058	---	0.0100
^{39}Y	0.0035	---	0.0050
^{40}Zr	0.0545	---	0.0300
^{56}Ba	0.0540	---	0.0500
^{60}Nd	0.0063	---	---
^{62}Sm	0.0012	---	---
^{72}Hf	0.0029	---	0.0006
^{82}Pb	0.0050	---	0.0010
^{83}Bi	0.0051	---	---
^{90}Th	0.0037	---	0.0005

Using soil composition B, the penetration of neutron into the soil was calculated for various water contents between 0 to 50% (Fig. 20), and for various soil densities varying from 0.5 to 2.0 g/cc (Fig. 21). The validity of these calculation and their sensitivity to soil composition was verified using soil A and making similar calculation as with soil B in which the source strength and source position were constant, although the flux was averaged over a different cell size. The agreement was very good, as shown with the line labeled "Alt. MCNP Calc" in the legend of Fig. 20.

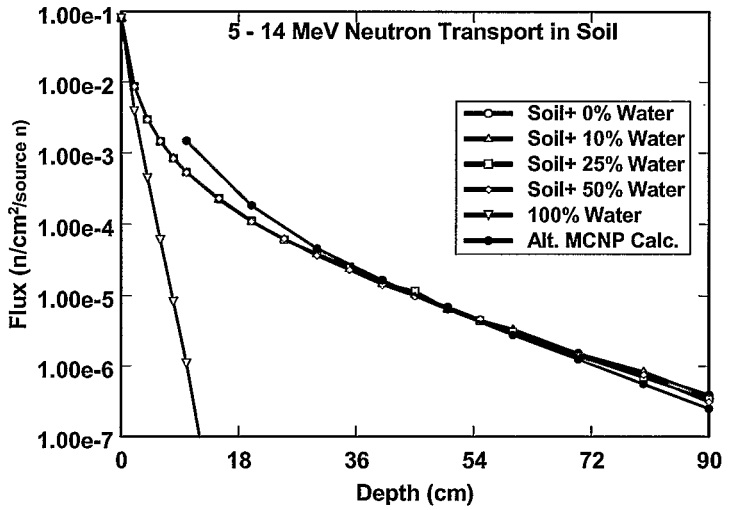


Figure 20. The neutron-flux intensities versus depth in soil for various water contents of soil are plotted. The solid squares represent calculations performed with different soil elemental.

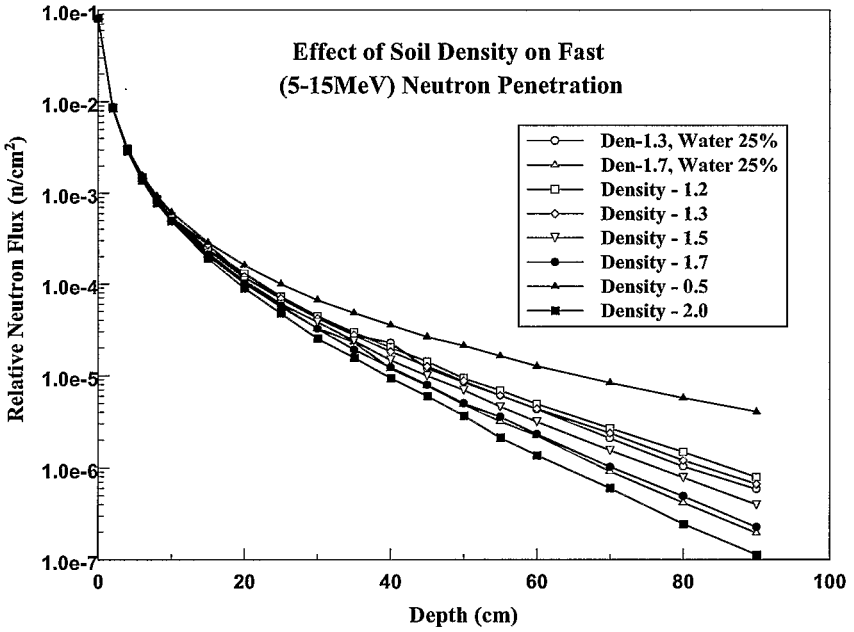


Figure 21. Distribution of fast neutron flux as a function of depth for soil of various soil densities.

6. ENVIRONMENTAL SAFETY and HEALTH (ES&H)

6.1 INSTRUMENT OPERATION

6.1.1 On Site (BNL) Use of the Instrument

Since INS system is based on neutron-induced nuclear reactions its usage must comply with the regulatory requirements for operating a radiation-generating device. We emphasize that it is an electrical device that does not produces radiation when turned off. In addition, although it contains about 2 Ci of tritium encased inside a vacuum tube inside a metal container pressurized up to 120 psi with SF_6 insulation gas, the Department of Transportation (DOT) does not require labeling it for transportation either by land or by air.

At Brookhaven National Laboratory, the Thermo Electron Corporation (Formerly MF Physics) Models A-325 and MP 320 Neutron Generators must be registered with the BNL Radiation Generating Device (RGD) Master Custodian, and conform to the requirements in the:

- BNL Radiological Control Division (RCD) Site Wide Standard Operation Procedure HP-SOP-028, Radiation Generating Devices, http://intranet.bnl.gov/rcd/procedures/HP-SOP/HP-SOP-028.docSBMS Subject Area, (https://sbms.bnl.gov/program/pd01/pd01d241.htm)
- 10 CFR 835 – Occupational Radiation Protection

The Principle Investigators (PI) Operators Manual, an Experimental Safety Review (ESR), and a Radiological Work Permit (RWP) govern operation of the device. The ESR is reviewed annually, and the RWP is issued annually.

Operators are required to wear dosimeters when operating the generator, and work areas are monitored both by routine survey and by passive thermoluminescent dosimetry. Operators are required to be trained Radiation Workers (RWT-002).

6.1.2 Off-Site Use of the Instrument

Shipment of the RGD by BNL is governed by SBMS procedures and must conform with the requirements in:

- SBMS subject area on Transport of Radioactive Materials. The BNL Point(s) of Contact are the Isotopes and Special Materials Group and the BNL Transportation Safety Officer, https://sbms.bnl.gov/standard/2y/2y00t011.htm.

In general, the shipment of the RGD must conform with the requirements in:

- 49 CFR 173 – Shippers – General Requirements for Shipments and Packagings
- 10 CFR Part 71 – Packaging and Transportation of Radioactive Material (For NRC Licensees)
- Applicable Agreement State Transportation Regulation

Use of the RGD would need to be regulated by either the U.S. Department of Energy, the Nuclear Regulatory Commission, or by a cognizant agreement state, depending under whose particular jurisdiction a given site is located by. .

During the operation of the neutron generator there are requirements for posting the surrounding area as a precaution to prevent radiation exposure; these can be found in http://www.access.gpo.gov/nara/cfr/waisidx_03/10cfr835_03.html. The second concern is the potential for soil activation due to irradiation with neutrons.

6.2 RADIOLOGICAL SURVEYS

6.2.1 Radiological Data

- Dose Fields
  Neutron and Gamma (N+γ) dose fields were measured with the Eberline SWENDI2 and Bicron microrem with low energy window. N+γ radiation dose fields varied with RGD operational voltages, but the typical dose rates observed are summarized in the following table (measurements are with no additional shielding around the generator):

Distance (inches)	Neutron (mRem/hr)	Gamma (mRem/hr)	Sum N + γ
1"	1100	200	1300
12"	400	50	450
60"	50	5	55
120"	6	0.5	6.5
600"	0.4	0.05	0.45

A fail-safe warning light must be on and highly visible from all approach paths to the unit when it is operational.

- Air Sampling
  A one hour air sample was taken (~2 cfm) within the High Radiation Area during generator's operation and the filter media was analyzed. Field counting the media found no activity greater than background levels.

- Soil Sampling
  Soil samples were taken adjacent to the RGD before operation, and after ~ 2.5 hours of operation. Although there appears to be a small amount of induced activity in the soil, the half-lives of isotopes found were relatively short, and induced activity was non-measurable after ~17 hours. (see attached analytical report). We note that this analytical report represents only the soil activated at this location and for a 2.5-hour activation time. Longer activation periods and variable soil compositions may produce different results.

6.2.2 Soil Activation

A preliminary assessment was completed of radioactive air emissions from quantifying the distribution of soil carbon *in situ* distribution based on nondestructive, inelastic scattering of fast neutrons. The measurement system will utilize a double sealed 14 MeV neutron generator H^3 (d,

n) He^4 accelerator to activate the soil. The potential activation products from $1x10^8$ neutrons sec^{-1} fluence were estimated in gram of sample size as follows:

Target Nucleus	Nuclide made	Half-life	Activity after 10 hours irradiation (uCi)
H-2	H-3	12.3 years	4.06E-10
C-12	C-11	20.3 minutes	5.63E-09
N-14	C-14	5736 years	2.92E-09
O-16	O-15	122 seconds	5.38E-09
Na-23	Na-22	2.602 years	4.73E-09
Fe-54	Fe-55	2.70 years	1.15E-04

Based on this source term, the synopsis report from CAP88-PC, version 2.0, modeling program provides a conservative estimate of effective dose equivalent of 4.48E-8 mrem/year to the Maximally Exposed Individual (MEI) located southeast at one-meter. The effective dose equivalent from the soil activation was well below 1% of the 10 mrem/year standard, and consequently, exempt from permitting requirements in accordance with 40 CFR 61.96 (b). Monte Carlo calculations combined with activation calculations by ORIGIN of the soil and of the iron shielding material are shown in Fig. 22a and Fig. 22b, respectively.

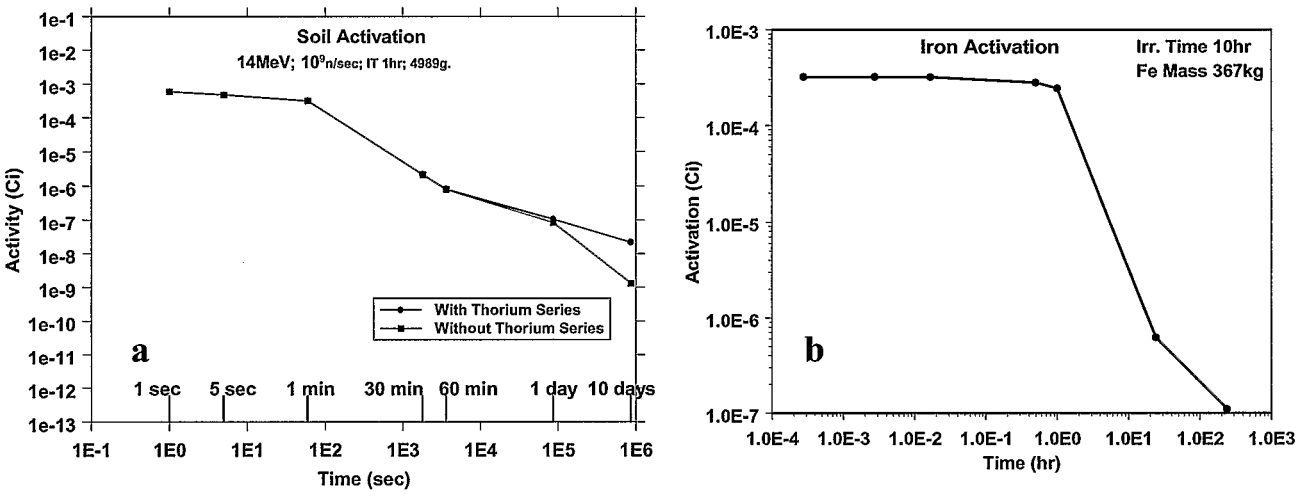


Figure 22. Monte Carlo calculation of soil activation (a) and iron shielding (b).

The soil calculations in Fig. 22a indicate that after a 1hr irradiation with neutron flux of 10^8 n/s, a mass of 4989 g, and waiting period of about 1hr the activity is at the natural background level. Activation of iron activation initially follows Mn activation, and for the conditions in Fig. 22b, activity is very low. Soil samples irradiated for 10 hr initially showed a low activity of Na at 1.05 Micro-Ci level that decayed according to its 14 hr half-life. In Fig. 23 we plot soil activation versus distance from the neutron generator.

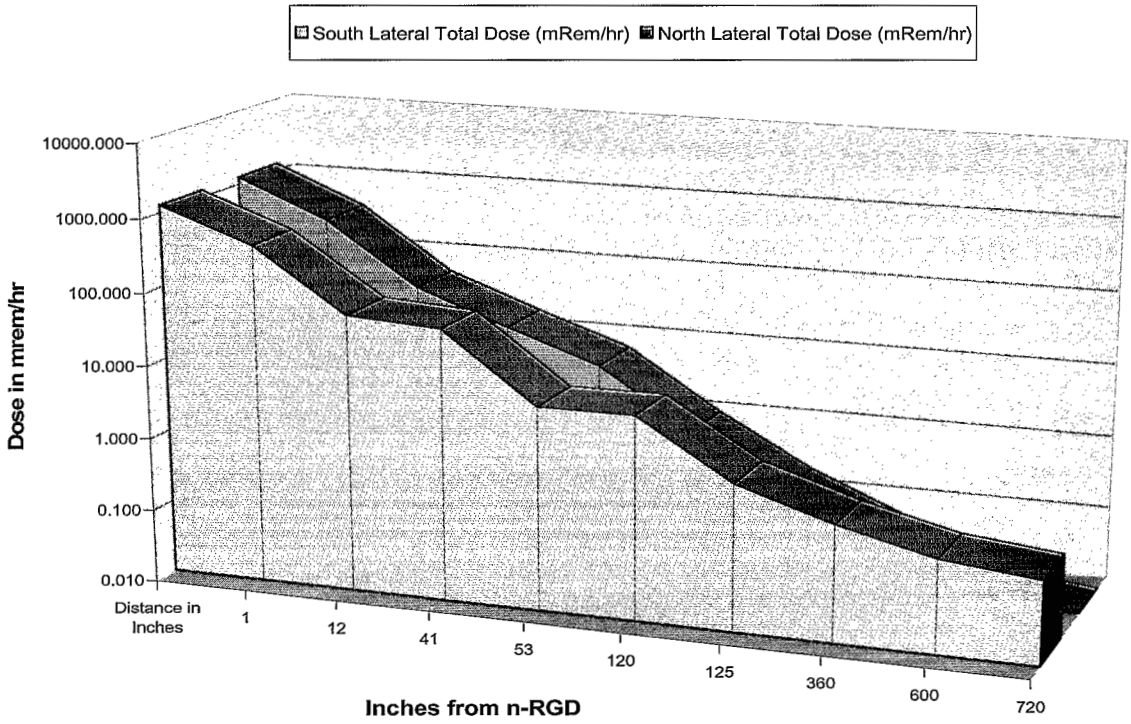


Figure 23. Dose rate as a function of the distance from the neutron generator.

6.3 POSTING

Typical, the posting requirements for the High Radiation Area boundary (>100 mRem/hr) must encompass the generator about 75 cm on each side, and for the Radiation Area boundary (>5 mRem/hr) be delineated at about 280 cm. These values were obtained without shielding of the neutron generator. They will be reduced with partial shielding of the field unit.

During irradiation, the immediate area surrounding the NG has to be posted and or attended by a health physicist. With the shadow shielding alone, i.e., no shielding on the other sides of the NG, the high radiation area boundary was posted at 24" from the source with the following readings; neutron dose rate 80 mrem/hr and gamma dose rate 3mr/hr. The radiation area boundary was posted at 254 cm with the following readings; neutron dose rate 4.5 mrem/hr and gamma dose rate 0.2 mr/hr. With additional shielding these areas will be reduced.

6.4 TRAINING REQUIREMENTS

The RGD produces a radiation field that requires radiological posting of the area surrounding the RGD. Entrants to the posted area must have requisite training to understand the nature of the hazards within the area. At BNL, where a mature radiological work program exists, entrants would require at a minimum, RWT-002A, Radiation Worker Training, to sign the Radiation Work Permit http://intranet.bnl.gov/rcd/procedures/FS-SOP/fs-sop-4027_R1.doc to access the area.

Personnel posting the area for radiation hazards must be qualified to do so, and to operate the survey equipment necessary to characterize the RGD's radiological footprint. Qualification requirements will depend on the regulatory agency governing the project (e. g., ANSI/ANS-31.-1993, 10 CFR 20, Qualified RSO).

6.5 Shipment Requirements

Two issues are involved with transporting the INS device. The first concerns the low level of tritium inside the acceleration tube of the neutron generator and second relates to the gas pressurized up to 120 psi in the acceleration tube enclosure. In the first case the requirements for shipping the neutron generator follow the International Air Transport Association (IATA) guidelines identification number UN2910 – Radioactive material, excepted package-instruments or articles. According to this regulation, labeling or posting of the package is not required except for providing proper information inside the package containing the neutron generator stating "This package conforms to the conditions and limitations specified in 49 CFR 173.424 for Radioactive Material, Excepted Package-Instrument or Articles UN2910."

For the pressurized vessel, according to the DOT's exemption on the web under the follow link (http://hazmat.dot.gov/exemptions/E13181.pdf) the neutron generator can be shipped by surface or air fully pressurized up to 120 psi.

7. FUTURE TASKS

We demonstrated the suitability of the alpha prototype system for detecting carbon in soil. However, to prepare the system for field use, further developments and system characterization are needed. The required tasks include developing the system, incorporating additional shadow shielding, establishing new calibration, determining the sampled volume, assessing the effects of soil density and moisture on instrument calibration, and also the effects of various soils on the instrument's response. The specific tasks are listed below:

1. Development of the device:

- Establish optimal height of the NG and the detection system above the soil.
- Introduce partial shielding around NG.
- Establish the device's final geometrical configuration (relative positioning of the detector and NG).
- Identify location of additional detectors.

2. Electronics:

- Increase the number of detectors to improve sensitivity.
- Replace the power supply and the controller for the NG.
- Use faster electronics for data acquisition.
- Identify the proper field power generator.

3. Calibration:

- Recalibrate the finalized system.
- Check the system's response to rocks or dead wood in the soil.
- Separately validate the effect the soil density correction.
- Assess the effect of soil moisture on system's calibration.
- Determine the effect of various soil types (need to identified) on carbon calibration.

Soil Laboratory Shed:

Significant progress was made in demonstrating the viability of the proposed INS method. However, the work is hampered considerably due to the lack of covered space wherein environmental conditions can be controlled. There is an urgent need to erect a temporary (moveable) laboratory-like shed enclosure in which soil samples of up to 50 ft^3 can be easily manipulated under controlled conditions using light machinery, and protected from temperature fluctuations and varying weather conditions. In this space, the INS system can be characterized and calibrated for various soil types, while at the same time engineering its design, and developing analytical algorithms before using it in the field.

8. DISCUSSION

We demonstrated the utility of the INS system to non-invasively measure carbon in soil. Normal levels of soil carbon in a pine stand and an oak forest were measured with a standard error of about 5% of the estimated carbon concentration; the low level of carbon in a sandy patch had a standard error of about 12%. These errors are due to counting statistics in the acquired spectrum. Extending the counting time and/or increasing the number of detectors can reduce the error. These errors do not include the variability in repositioning the system or the normal variability in the soil's carbon content both laterally and with depth. Furthermore, optimizing the system's configuration will reduce the counting error even more. Thus, incorporating improvements will increase the sensitivity of the system and reduce the minimum detection limit (MDL). At present, the MDL for a counting time of 30 min is about 0.018 gC/cc, (or, assuming a soil bulk density of 1.5 g/cc, the MDL is 1.2% C by weight). The sensitivity of the system was highlighted in measurements taken in the pine stands. Thus, although the litter on top of the soil was not included in the chemical analysis, the INS carbon signal clearly differed with and without the litter. The error in the chemical analysis of carbon in the soil varied between 8 and 28 percent representing lateral variability in carbon concentration in the soil over an area of one square foot.

The INS method represents a large savings in time and effort. Presently, using the INS method it took one person three hours to set the system at three sites and to acquire the data. An additional two hours were required to analyze the data. In future, the spectral analysis will be automated and performed virtually instantaneously at the end of data acquisition. In comparison, the chemical analysis involved at least three persons for about six hours in taking core samples and packing them for shipping. Subsequently, the partitioned core samples had to be prepared for chemical analysis in which the drying protocol alone requires 24 hours. So, about three to four days (28 work hours) of intensive labor are required for analyzing 75 samples from all three sites. The reduction in labor involved in scanning many sites is nearly ten fold, while the speed of returning carbon data on concentration is seconds versus days. Using the INS method in this early prototype configuration, it would be possible during an eight hours day to analyze about 12 sites and to have all of the concentration analyses in hand at the end of the day.

Based on current thirty minutes counting statistics with an error of about 6% at approximate carbon levels of 80 mgC/cc, a change in C at 3-sigma confidence level corresponds to a change of 18%. However, improving the counting statistics will lower the detectable change, while maintaining the same confidence level. For example, a five-hour counting time will reduce the detectable change at 3-sigma level to 5.7%. Any additional improvements in the signal-to-noise ratio will reduce further the detectable minimal change.

The capability to measure additional elements is apparent in the measured inelastic and prompt gamma spectra presented. It is of special interest to ecologists, agronomists, and foresters that the INS technique can simultaneously quantify total soil nitrogen. Offering these capabilities would require additional optimization of signal processing and as well as independent calibration lines.

In conclusion, the INS system is a safe, low-cost, and rapid tool to quantify carbon in soil. It is completely non-invasive so that identical points can be sampled year after year. The effort required to obtain soil carbon data with INS is one-tenth that required by traditional methods and the time required to have reportable values is nearly instantaneous. Further work is needed to

develop calibrations for a variety of soil types and conditions, and to improve system;s geometry and post-processing of data.

9. PUBLICATIONS and PRESENTATIONS

9.1 PUBLICATIONS:

1. Wielopolski L., Orion I., Hendrey G., and Roger H., (2000), Soil Carbon Measurements Using Inelastic Neutron Scattering, IEEE Trans. Nucl. Sciences, 47 (2000) 914-917.
2. Wielopolski L., Hendrey G., Daniels J., and McGuigen M., (2000), Imaging Tree Root Systems In Situ, In Eigth Intl. Conference on Ground Penetrating RADAR, Noon DA, Stickley GF, Longstaff D, SPIE 4084 (2000) 642-646.
3. Wielopolski L., Mitra S., Hendrey G., Rogers H., Torbert A., and Prior S., (2003), Non-Destructive *In situ* Soil Carbon Analysis: Principle and Results. Proceedings of the Second Annual Conference on Carbon Sequestration, May 3-5 (2003), Article No. 225.

Submitted:

1. S. Mitra, L. Wielopolski, G. Hendrey, Comparison of a digital versus an analog signal processing system for neutron inelastic gamma ray spectrometry, Applied Radiation and Isotopes. 10/2003.
2. Lucian Wielopolski, Zhiguang Song, Itzhak Orion, Albert L. Hanson, George Hendrey, Considerations for Monte Carlo Calculations in Soil, Applied Radiation and Isotopes, 10/2003.
3. Lucian Wielopolski, Richard B. Hoover, Sudeep Mitra, Search for Elemental and Mineral Biomarkers Using Inelastic neutron Scattering Induced Gamma Spectroscopy, SPIE-ASTRO-Biophysics. 10/2003.

9.2 PRESENTATIONS:

1. Wielopolski L. DOE/OBER Environmental Science Division Presentation. "Novel Methods for Non-Destructive Root System Imaging and Carbon Detection In Situ", Germantown, Maryland, January 21st, 1999.
2. Wielopolski L. Invited talk on The status of the root systems imaging and why do we care. University of Connecticut, Department of Geology & Geophysics, Storrs CT February 4th, 1999.
3. Wielopolski L. FACE Coordination Meeting, "New Tools for Non-Invasive Measurements of Soil Carbon". Washington DC, March 15-16, 1999.
4. Wielopolski L. White House Climate Change Task Force, Carbon Sinks Meeting, (Invited Presentation) "In Situ Nondestructive Soil Analysis, Imaging and Testing, Washington DC, April 8th, 1999.
5. Wielopolski L. Joint Science Team Meeting TCP, PER, & NIGEC, "Direct Non-Destructive, In-Situ Techniques to Measure Belowground Processes", Indianapolis, Indiana June 3-4, 1999.
6. Wielopolski L. University of Montana School of Forestry, Invited talk on Soil Noninvasive In Situ Elemental Analysis and Root Systems Imaging. Missoula, MT, June 17th, 1999.

7. Wielopolski L. DOE Federal Energy Technology Center Presentation. "Novel Method for Non-Destructive Carbon Detection In Situ", Pittsburgh Pennsylvania, October 7th, 1999.
8. Wielopolski L. IEEE 1999 Nuclear Science Symposium. "Soil Carbon Measurement Using Inelastic Neutron Scattering", Seattle, Washington, October 24-30, 1999.
9. Wielopolski L. Duke University, Department of Botany, The Phytotron, Invited talk, "Non-Invasive Soil Analysis", Durham, NC., February 4th, 2000.
10. Wielopolski L. Argonne National Laboratory, DOE Terrestrial Science Team Meeting (TCP, PER, NIGEC, AmeriFlux, C sequestration), *In* Situ Non-Destructive Soil Carbon Measurement: Principle & Feasibility, Argonne National Laboratory, Argonne, Illinois, October 29-31, 2001.
11. Wielopolski L. Argonne National Laboratory, DOE Terrestrial Science Team Meeting (TCP, PER, NIGEC, AmeriFlux, C sequestration), Calibration Of An Inelastic Neutron Scattering System For Carbon Analysis In The Field, Argonne National Laboratory, Argonne, Illinois, October 29-31, 2001.
12. Wielopolski L. United States Department of Agriculture, National Soil Dynamics Laboratory, "In Situ Soil Carbon Measurement", (Invited Presentation) NSDL, Auburn Al, January 31, 2002.
13. Wielopolski L. Brookhaven National Laboratory, Environmental Sciences Department, "Non-invasive In Situ Carbon Measurement in Soil", BNL Upton NY, September 11th, 2002.
14. Wielopolski L. DOE Office of Biological and Environmental Research, "*In Situ* Noninvasive Soil Carbon Measurement," Germantown, MD October 10th, 2002.
15. Wielopolski L. DOE National Energy and Technology Laboratory, "In-Situ Non-Invasive Soil Carbon Measurement", Morgantown, West Virginia, October 28th, 2002.
16. Wielopolski L. University of Tennessee, Biosystems Engineering & Environmental Sciences, "Non-intrusive Carbon Determination in Soils," (invited talk), Knoxville, TN January 16th 2003.
17. Wielopolski L. NSF – Belowground Biomass and Biogeochemistry Workshop. "New Advances in Belowground C Measurements," (invited talk), Arlington VA, February 20th, 2003.
18. Wielopolski L. The International Symposium on Optical Science and Technology SPIE's 48th Annual Meeting, Astronomical Optics and Instrumentation, Conference on Instruments, Methods, and Missions for Astrobiology, "Search for Elemental and Mineral Biomarkers Using Inelastic neutron Scattering Spectroscopy (INSS)," San Diego California, 3-8 August 2003.
19. Mitra S. 226th ACS National Meeting of the American Chemical Society, Division of Geochemistry, "Use of a Digital Signal Processing System for Neutron Inelastic Gamma-Ray Spectroscopy," New York City, NY, September 7-11, 2003.
20. Hendrey GR. 226th ACS National Meeting of the American Chemical Society, Division of Geochemistry, "Noninvasive, *In* situ Quantification of Soil Carbon Sequestration." New York City, NY, September 7-11, 2003.
21. Wielopolski L. Consortium for Agricultural Soils Mitigation of Greenhouse Gases (CASMGS), Fall Forum: Measuring and Monitoring Carbon, "Non-Destructive *In Situ* Soil Carbon Analysis: Principle and Results." Kansas State University in Manhattan, KS, October 15-17, 2003.

22. Wielopolski L. Carbon Cycle and Carbon Sequestration Program (TCP), Annual Meeting,, "Non-Destructive *In Situ* Soil Carbon Analysis: Principle and Results." Boulder CO, October 16-17, 2003.
23. Mitra S. Carbon Cycle and Carbon Sequestration Program (TCP), Annual Meeting,, "Enhanced *In Situ* Soil Carbon Analysis Using Multiple Detection System." Boulder CO, October 16-17, 2003.
24. Wielopolski L. Annual Meeting of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, "Non-Destructive Determination of Soil Carbon in Large Fields", Denver CO, November 2-6, 2003.
25. Denton P. Annual Meeting of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, "A System for Rapid Determination of Plant Potassium Content", Denver CO, November 2-6, 2003.

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11. APPENDICES

Appendix A	**Calibration spectra from the sand pit.**
Appendix B	**Field spectra**
APPENDIX C	**Analysis of calibration data**
APPENDIX D	**Analysis of field data**
APPENDIX E	**Spectral plots**
APPENDIX F	**Chemical Analysis of Soil Cores Data**

APPENDIX A

Sandpit calibration (Sand,0%C):"Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	0	21613	170690	335980	455585	422632	437496	431953	329668
Ch 11	299597	269271	246028	238710	255389	281445	340660	517141	566977	379351
Ch 21	244240	196863	192892	204185	194191	174545	165631	164677	154725	143337
Ch 31	137566	134698	131205	124152	117964	116321	117287	114993	110607	107074
Ch 41	104154	102887	101348	99969	99938	98370	96492	92115	88445	84903
Ch 51	83604	81358	79967	78404	76369	76245	75124	75271	73003	70198
Ch 61	69623	72155	78977	83024	80057	71924	63906	58692	56477	54833
Ch 71	53697	53210	53010	51855	51726	52107	51812	52360	52681	51485
Ch 81	50136	48584	46570	45025	44163	43047	42392	41850	41614	41471
Ch 91	41182	40878	40860	39966	39724	39432	39149	39140	38469	37695
Ch 101	36868	35923	34878	34312	33358	33229	33182	33213	33082	32119
Ch 111	31972	31028	31039	30698	29976	29338	28958	28155	28144	27502
Ch 121	26919	26861	26528	26074	25706	25805	25980	26286	26519	26721
Ch 131	26966	26205	25700	25256	24887	24466	24048	23702	23138	22537
Ch 141	22203	21300	21353	21053	20925	20507	19812	19966	19768	19251
Ch 151	19333	18924	18785	19018	18974	19112	19262	19339	19306	18988
Ch 161	18611	18465	18068	17861	17453	17358	17081	17049	16766	16928
Ch 171	16630	16603	16760	16689	16817	16628	16656	16910	16751	16675
Ch 181	16597	16426	15909	15840	15807	15498	15328	15433	15262	15290
Ch 191	15224	15220	15624	15720	16542	16606	17077	17413	17225	16830
Ch 201	16074	15946	15688	15343	14715	14789	14516	14375	14217	14582
Ch 211	14872	15472	16180	16793	17369	17571	17318	16351	15444	14898
Ch 221	14058	14079	13951	13744	13658	13448	13173	12796	12174	12264
Ch 231	11950	11702	11633	11037	11035	10755	11021	11102	11471	12025
Ch 241	12340	12341	12253	11817	11237	10702	9988	9319	8539	8072
Ch 251	7706	7011	6596	6111	5665	5500	5035	4859	4780	4676
Ch 261	4463	4321	4162	4126	4020	3954	3624	3554	3502	3438
Ch 271	3178	3221	3139	3145	3118	2978	2974	2943	2832	2810
Ch 281	2762	2709	2686	2569	2477	2425	2372	2357	2303	2284
Ch 291	2242	2294	2193	2207	2052	2048	2118	2090	2086	2079
Ch 301	1876	1846	1952	1871	1754	1875	1694	1732	1772	1717
Ch 311	1688	1751	1707	1626	1561	1523	1527	1541	1408	1352
Ch 321	1357	1275	1315	1342	1263	1151	1191	1178	1209	1177
Ch 331	1161	1091	1045	1069	1007	1021	934	922	901	836
Ch 341	885	870	750	842	780	773	739	748	672	692
Ch 351	693	636	617	617	615	653	579	566	517	576
Ch 361	575	550	516	529	450	526	478	460	466	480
Ch 371	489	439	424	414	397	393	382	364	377	366
Ch 381	366	338	310	294	316	298	293	288	284	241
Ch 391	273	279	255	244	261	232	211	200	241	234
Ch 401	192	208	222	177	172	209	179	153	164	175
Ch 411	174	155	154	153	161	131	122	144	127	137
Ch 421	128	114	113	122	119	111	123	118	99	105
Ch 431	109	107	104	88	86	99	92	92	71	97
Ch 441	92	76	66	91	68	82	81	79	77	70
Ch 451	65	72	54	76	59	80	51	61	62	67
Ch 461	52	45	51	48	52	48	31	70	45	59
Ch 471	52	44	48	41	30	34	46	43	38	32
Ch 481	43	35	43	29	38	35	22	39	34	37
Ch 491	21	27	28	32	29	35	39	21	38	31
Ch 501	28	30	26	24	20	28	34	25	29	21
Ch 511	27	26								

Sandpit calibration (Sand, 0%C): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	12	4798	74699	161487	247860	249627	199287	174160	160703
Ch 11	148791	138075	128407	123529	121684	121073	150895	282884	300100	164529
Ch 21	110746	98112	88384	86470	85258	82787	81831	80297	79754	79991
Ch 31	78667	76488	75532	74072	71463	70243	68852	67614	66896	64528
Ch 41	62248	60321	58735	57117	55672	54586	52773	50918	48074	47110
Ch 51	44955	43130	41834	39206	36409	34165	31826	30425	28715	27041
Ch 61	25897	25615	26863	27075	25121	20485	17167	15313	13950	13213
Ch 71	12253	11874	11605	11526	11316	11061	10933	11204	11300	11379
Ch 81	10924	10383	9880	9579	9432	9559	9434	9303	9495	9449
Ch 91	9321	9502	9252	9436	9103	8764	8560	8530	8524	8328
Ch 101	7989	7937	7844	7718	7695	7621	7812	7855	7677	7685
Ch 111	7318	7289	7330	7030	7066	6810	6778	6560	6415	6435
Ch 121	6457	6582	6962	7097	7398	7496	7005	6539	6311	6031
Ch 131	5631	5512	5633	5380	5422	5428	5280	5352	5210	5158
Ch 141	5104	5062	4878	5020	4993	4891	4847	4824	4805	4774
Ch 151	4736	4821	4824	4980	4889	5135	5014	4951	4870	4752
Ch 161	4519	4453	4474	4335	4358	4330	4162	4211	4211	4323
Ch 171	4532	4687	5052	5081	4965	4788	4480	4120	4071	3879
Ch 181	3721	3690	3634	3599	3496	3398	3393	3403	3381	3352
Ch 191	3318	3298	3392	3359	3327	3560	3603	3698	3570	3631
Ch 201	3367	3362	3239	3227	3227	3129	2996	3100	2933	3047
Ch 211	3026	3181	3276	3373	3527	3444	3226	3133	2888	2846
Ch 221	2642	2629	2676	2536	2458	2465	2350	2175	2023	1984
Ch 231	1855	1802	1718	1736	1743	1720	1803	1855	1883	1968
Ch 241	1939	1974	1946	1787	1588	1363	1307	1211	1109	963
Ch 251	865	832	683	628	614	539	471	387	352	339
Ch 261	312	324	327	350	370	411	422	422	399	386
Ch 271	361	314	257	248	216	198	222	177	175	173
Ch 281	156	156	169	140	135	120	118	148	113	96
Ch 291	114	125	121	135	120	128	148	122	139	107
Ch 301	115	89	81	87	69	79	62	71	68	62
Ch 311	62	48	71	79	61	56	55	61	57	37
Ch 321	41	45	55	34	35	32	46	29	30	25
Ch 331	29	33	23	27	24	16	16	32	24	30
Ch 341	18	10	22	14	24	26	20	18	28	29
Ch 351	21	24	18	20	9	12	18	16	19	15
Ch 361	13	16	13	18	17	22	12	14	15	15
Ch 371	19	10	22	18	11	10	13	15	10	13
Ch 381	11	12	13	6	6	8	7	3	6	9
Ch 391	12	13	8	10	10	10	13	13	13	8
Ch 401	9	7	6	13	6	10	5	5	9	8
Ch 411	5	10	4	9	9	9	13	7	7	5
Ch 421	6	5	6	6	9	9	8	5	11	8
Ch 431	6	7	5	9	5	3	4	6	4	4
Ch 441	10	4	7	13	8	4	12	3	7	8
Ch 451	9	5	4	8	8	4	6	5	3	5
Ch 461	1	6	5	5	4	11	5	6	6	4
Ch 471	2	9	1	8	2	5	0	7	4	4
Ch 481	2	5	5	2	3	3	4	0	6	7
Ch 491	5	4	7	5	9	6	9	3	5	2
Ch 501	5	5	1	9	5	9	4	2	5	5

Ch 511		0	11							

SANDPIT CALIBRATION (SAND + 2.5% C): "INELASTIC" GAMMA RAY SPECTRUM, LIVE TIME: 1800S

Ch 1	0	445	121507	305021	370384	441054	407217	408876	395526	306545
Ch 11	277390	248288	226446	219462	232821	253534	302574	463356	510605	338895
Ch 21	214102	170719	167494	177542	169405	151561	144326	142558	133655	123902
Ch 31	118324	116740	112347	106737	100815	100113	100792	99059	95410	92013
Ch 41	88858	87940	85895	86000	85249	84065	82058	78266	74967	72205
Ch 51	70087	69264	68018	65991	64487	63810	64052	64105	62277	59541
Ch 61	58739	60834	66324	70260	68565	61210	53639	49386	47196	46198
Ch 71	45201	44772	44274	44038	44029	43818	44185	44167	44523	43853
Ch 81	42717	40908	39123	37983	37130	35903	35821	35198	35217	34931
Ch 91	34645	34636	34678	34224	33692	33567	32815	32443	32714	32051
Ch 101	31239	29953	29227	28165	28054	27967	28096	27776	27448	27223
Ch 111	26776	26609	25904	25654	24786	24670	23966	23605	23197	23094
Ch 121	22763	22183	22074	21659	21603	21504	21883	21903	22001	22401
Ch 131	22149	22059	21402	21170	21201	20324	20114	19807	19320	18984
Ch 141	18727	18255	17690	17177	16880	16806	16745	16379	16373	15857
Ch 151	15469	15446	15645	15706	15903	16287	16418	16214	15927	15876
Ch 161	15360	15126	14639	14524	14344	14120	13800	13749	13598	13680
Ch 171	13331	13472	13377	13480	13348	13556	13625	13924	13696	13435
Ch 181	13734	13210	13012	12939	12662	12469	12387	12264	12302	12100
Ch 191	12119	12052	12317	12591	12727	13467	13864	14158	13873	13724
Ch 201	13304	12921	12617	12230	11949	11766	11534	11247	11511	11450
Ch 211	11693	12402	13254	13677	14136	14443	14182	13459	12773	11973
Ch 221	11627	11259	10968	10892	10761	10380	10336	10069	9806	9791
Ch 231	9443	9211	8883	8819	8698	8511	8498	8757	8838	9201
Ch 241	9589	9751	9661	9295	8753	8355	7962	7314	6902	6429
Ch 251	5930	5781	5195	4865	4513	4150	3963	3830	3612	3540
Ch 261	3459	3335	3285	3096	2986	2829	2838	2844	2712	2581
Ch 271	2531	2387	2395	2427	2306	2294	2234	2226	2191	2262
Ch 281	2143	2136	2052	1910	1987	1934	1853	1735	1782	1756
Ch 291	1873	1716	1679	1695	1630	1655	1616	1596	1567	1580
Ch 301	1534	1475	1404	1412	1400	1360	1391	1348	1365	1350
Ch 311	1301	1300	1276	1290	1207	1231	1112	1105	1138	1102
Ch 321	1010	1020	1006	977	937	917	930	875	850	825
Ch 331	809	872	791	760	746	703	707	716	618	670
Ch 341	609	625	624	585	600	551	599	582	608	529
Ch 351	506	547	465	491	470	427	411	458	380	377
Ch 361	399	346	362	396	379	323	343	356	350	317
Ch 371	284	312	257	312	291	281	304	258	252	265
Ch 381	241	231	242	233	222	204	209	188	189	196
Ch 391	178	155	179	171	157	140	168	194	153	145
Ch 401	134	123	119	118	132	133	120	121	108	105
Ch 411	124	103	90	102	90	102	105	90	86	72
Ch 421	86	74	98	83	70	69	77	65	70	88
Ch 431	67	68	55	58	79	53	58	66	55	53
Ch 441	58	57	49	55	52	49	36	43	50	47
Ch 451	50	34	37	47	33	32	41	30	34	35
Ch 461	40	27	38	30	33	28	31	30	29	26
Ch 471	29	29	28	25	44	34	44	35	24	28
Ch 481	12	26	29	25	19	28	24	18	22	16
Ch 491	12	19	20	27	23	16	15	18	24	27

Ch 501	19	18	17	26	19	27	18	10	10	8
Ch 511	15	19								

Sandpit calibration (Sand + 2.5 % C): Prompt gamma ray spectrum, Live time: 1800 s

Ch 1	0	531	41009	164629	221336	262742	253973	222710	199555	181515
Ch 11	167833	153899	143325	136226	133432	133075	159384	285954	303959	178645
Ch 21	121200	104103	89617	87780	86209	82268	80441	78819	77582	77716
Ch 31	75590	73404	71413	69645	67512	66647	64966	64195	62963	60320
Ch 41	58418	56933	54945	53833	53048	52140	50491	48328	46591	45249
Ch 51	44197	42397	40401	38502	35774	33390	32616	31044	29285	28075
Ch 61	27480	27854	29295	29857	27407	23924	20221	18461	17140	16440
Ch 71	15940	15377	15181	15239	15411	15115	15257	15678	16125	16110
Ch 81	15133	13718	13029	12459	12294	12285	12327	12220	11998	11994
Ch 91	12010	11910	11934	11984	11720	11493	11206	10909	10755	10697
Ch 101	10330	9914	9778	9819	9741	9979	10167	10158	10180	9771
Ch 111	9625	9306	8966	8775	8628	8529	8246	8248	7852	7948
Ch 121	7875	8156	8900	9433	9921	9726	9304	8558	8005	7245
Ch 131	6900	6667	6485	6517	6344	6285	6289	6217	6180	5990
Ch 141	6007	5911	5797	5679	5814	5797	5690	5679	5613	5438
Ch 151	5436	5521	5542	5732	6023	6221	6058	5880	5791	5452
Ch 161	5378	5165	5082	5017	4846	4643	4638	4621	4822	5024
Ch 171	5256	5724	6093	6257	6106	5797	5248	4858	4440	4317
Ch 181	3985	3825	3836	3901	3763	3667	3744	3594	3641	3452
Ch 191	3511	3538	3467	3551	3593	3612	3675	3701	3715	3824
Ch 201	3590	3429	3417	3364	3375	3281	3232	3207	3212	3130
Ch 211	3075	3390	3472	3564	3706	3605	3358	3211	2910	2812
Ch 221	2631	2664	2534	2587	2576	2404	2344	2274	2056	2077
Ch 231	1882	1852	1804	1798	1860	1809	1892	1829	1924	1955
Ch 241	1968	1930	1845	1720	1686	1443	1435	1341	1269	1249
Ch 251	1242	1108	1121	1043	940	785	767	667	579	579
Ch 261	550	537	511	528	569	615	621	642	628	574
Ch 271	532	524	481	431	382	348	330	330	302	315
Ch 281	258	265	243	236	220	237	205	229	191	212
Ch 291	194	196	224	250	227	240	266	244	217	199
Ch 301	205	140	149	173	136	147	135	135	120	123
Ch 311	118	118	128	101	136	95	92	107	82	96
Ch 321	73	68	76	71	76	74	75	67	72	58
Ch 331	68	46	50	68	56	45	55	47	55	39
Ch 341	41	34	30	32	33	45	38	42	37	37
Ch 351	44	41	47	37	38	29	25	35	33	31
Ch 361	23	26	31	29	20	40	26	30	37	34
Ch 371	33	22	25	29	17	20	18	19	17	10
Ch 381	19	14	16	13	18	13	17	20	17	7
Ch 391	16	13	13	17	9	17	15	11	6	6
Ch 401	15	6	10	16	15	13	10	9	16	8
Ch 411	16	8	12	12	6	9	9	14	6	9
Ch 421	12	10	10	7	7	10	10	11	10	8
Ch 431	14	10	3	4	8	6	5	9	14	10
Ch 441	5	6	5	10	8	7	5	8	5	8
Ch 451	8	4	3	6	8	5	6	6	7	6
Ch 461	5	4	4	4	9	2	2	5	6	5
Ch 471	4	1	6	4	9	8	6	7	7	7
Ch 481	7	7	3	9	4	7	5	7	4	10
Ch 491	10	7	8	7	7	8	10	3	6	1
Ch 501	6	10	2	9	5	7	4	3	7	6

Sandpit calibration (Sand + 5 % C): "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	5305	152985	308170	366557	425038	390574	401706	397679	310287
Ch 11	280635	252246	230276	222159	235716	254275	299050	438582	501574	358845
Ch 21	233687	184458	176547	185285	177673	159166	150164	148238	139597	130132
Ch 31	124076	121129	117276	111968	106006	103964	104146	102795	99523	94975
Ch 41	93471	91100	89678	89004	88525	86964	85444	82681	78691	75840
Ch 51	73924	72596	70982	69333	67890	66988	67079	66985	65968	63621
Ch 61	61517	63644	68178	72727	72615	65972	58643	53605	51277	49616
Ch 71	48935	48530	47297	46644	47081	46800	46544	47229	47112	46581
Ch 81	45883	43770	42597	41036	39709	38876	38418	37781	37238	37072
Ch 91	37182	36985	36792	37122	36052	35382	35241	35051	34444	34363
Ch 101	33822	32947	31845	30883	30456	30095	30110	29833	29723	29063
Ch 111	28725	28350	28399	27515	27343	26437	25738	25404	25311	24920
Ch 121	24414	24223	23609	23572	23233	23086	23051	23367	23483	23788
Ch 131	23858	24105	23626	22909	22454	22068	21786	21388	21365	21078
Ch 141	20481	19766	19425	19436	18742	18674	18123	17839	17570	17571
Ch 151	17098	16919	16910	16765	16972	17701	17764	17625	17493	17326
Ch 161	17015	16518	16377	15896	15402	14956	15254	14871	14513	14367
Ch 171	14491	14350	14509	14678	14667	14521	14593	14674	14537	14783
Ch 181	14510	14378	14172	14251	13544	13574	13213	13215	13045	13051
Ch 191	13347	13077	13204	13555	13626	14182	14372	15028	14995	14889
Ch 201	14503	14317	13602	13398	13028	12792	12596	12488	12304	12156
Ch 211	12491	13119	13311	14170	14811	15391	15258	14960	14629	13565
Ch 221	12807	12192	12012	11716	11721	11505	11168	11252	10990	10798
Ch 231	10366	10215	9958	9647	9629	9315	9312	9201	9411	9746
Ch 241	10044	10254	10163	10134	10049	9602	9109	8505	8080	7768
Ch 251	7207	6764	6333	6050	5657	5133	4919	4557	4545	4337
Ch 261	4135	3970	3868	3801	3640	3563	3413	3336	3122	3059
Ch 271	2956	3022	2856	2794	2797	2763	2711	2593	2685	2600
Ch 281	2517	2407	2400	2347	2288	2264	2230	2065	2105	2062
Ch 291	2062	2010	1925	1958	1959	1915	1884	1830	1769	1860
Ch 301	1765	1710	1699	1702	1592	1654	1588	1544	1562	1519
Ch 311	1519	1505	1465	1409	1429	1372	1422	1288	1343	1240
Ch 321	1187	1201	1178	1188	1116	1111	1092	1098	1009	1048
Ch 331	1042	930	962	907	929	912	873	818	821	764
Ch 341	764	786	772	709	729	707	701	689	643	632
Ch 351	591	635	548	598	520	497	538	525	506	471
Ch 361	495	482	483	526	432	487	430	408	410	385
Ch 371	378	368	338	341	357	323	315	387	324	302
Ch 381	317	346	299	298	279	263	246	250	230	257
Ch 391	230	244	227	223	237	208	216	158	184	185
Ch 401	188	175	184	170	166	158	174	170	162	145
Ch 411	134	125	128	123	121	99	100	122	110	105
Ch 421	118	109	90	107	101	99	96	92	87	77
Ch 431	87	95	88	101	78	88	80	78	78	78
Ch 441	62	70	69	69	72	74	55	56	64	61
Ch 451	65	54	59	51	49	65	49	49	59	56
Ch 461	59	43	47	43	51	43	47	37	41	38
Ch 471	56	33	41	41	44	31	43	34	46	40
Ch 481	46	31	22	40	32	30	32	29	25	31
Ch 491	28	22	35	27	35	28	22	24	17	21
Ch 501	24	29	21	26	29	23	27	24	18	25

Ch 511 23

Sandpit calibration (Sand + 5 % C): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	1261	40740	157636	210088	250831	250540	216841	189586	173933
Ch 11	158382	148154	135065	127723	122338	120796	141079	262767	308850	183429
Ch 21	115187	95848	79228	75052	74621	71531	69731	67743	66891	66387
Ch 31	64888	62498	61553	60382	58432	56697	55799	54410	53782	52696
Ch 41	50432	48979	47684	47074	45725	44607	43716	42552	40436	39672
Ch 51	38729	37096	35766	33984	32190	29959	28401	27166	26329	25483
Ch 61	24431	24308	25315	26703	26067	22789	19532	17272	15798	15350
Ch 71	14562	14302	13948	13904	14018	14024	13804	14085	14564	14586
Ch 81	14419	13343	12288	11738	11386	11687	11431	11354	11197	11187
Ch 91	11063	10936	11321	11215	11008	10740	10611	10386	10060	10035
Ch 101	9624	9505	9294	9150	9068	9226	9476	9647	9633	9369
Ch 111	9323	8972	8879	8568	8505	8246	8104	7881	7722	7650
Ch 121	7511	7550	7930	8614	9234	9642	9441	8984	8055	7121
Ch 131	6728	6616	6456	6129	6035	6065	5970	5969	5999	5886
Ch 141	5666	5737	5417	5519	5565	5530	5331	5342	5157	5258
Ch 151	5281	5101	5355	5198	5489	5953	5914	5954	5782	5483
Ch 161	5329	5166	5002	4989	4866	4690	4550	4548	4527	4527
Ch 171	4764	5028	5547	6065	6245	6071	5840	5375	4763	4303
Ch 181	4033	3830	3693	3631	3521	3585	3583	3444	3503	3327
Ch 191	3397	3251	3311	3286	3285	3382	3477	3509	3501	3575
Ch 201	3395	3162	3353	3245	3110	3140	3121	3072	3052	2918
Ch 211	2921	2869	2944	3076	3197	3295	3262	3196	2976	2861
Ch 221	2559	2487	2487	2511	2426	2501	2337	2238	2149	1971
Ch 231	1881	1842	1774	1644	1619	1538	1667	1687	1777	1677
Ch 241	1807	1761	1700	1684	1694	1503	1480	1290	1187	1189
Ch 251	1085	1087	1069	1005	1026	885	807	681	637	547
Ch 261	516	444	415	411	454	460	484	492	546	510
Ch 271	543	531	527	457	408	363	333	295	270	244
Ch 281	218	225	193	223	176	177	179	171	150	129
Ch 291	139	134	159	167	140	157	182	200	178	198
Ch 301	161	152	132	121	104	85	87	78	69	76
Ch 311	79	72	71	62	59	71	76	69	80	56
Ch 321	49	57	39	47	48	33	40	40	45	46
Ch 331	47	31	39	26	20	31	28	20	15	20
Ch 341	11	21	20	22	23	25	13	15	20	26
Ch 351	25	17	19	20	24	15	24	22	27	22
Ch 361	23	16	14	14	14	7	8	17	21	19
Ch 371	19	15	17	18	15	20	12	10	11	15
Ch 381	9	6	11	19	15	7	16	9	13	7
Ch 391	5	5	8	15	6	6	11	7	9	7
Ch 401	2	9	5	10	8	9	2	13	2	5
Ch 411	4	8	4	4	10	8	5	5	4	8
Ch 421	6	9	6	8	7	3	5	6	6	5
Ch 431	3	9	4	8	6	5	6	10	7	9
Ch 441	62	70	69	69	72	74	55	56	64	61
Ch 451	65	54	59	51	49	65	49	49	59	56
Ch 461	59	43	47	43	51	43	47	37	41	38
Ch 471	56	33	41	41	44	31	43	34	46	40
Ch 481	46	31	22	40	32	30	32	29	25	31
Ch 491	28	22	35	27	35	28	22	24	17	21

Ch 501	24	29	21	26	29	23	27	24	18	25
Ch 511	23	20								

Sandpit calibration (Sand, 10%C): "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	6129	173127	345445	415603	454015	409236	421487	416424	324382
Ch 11	293558	265432	242272	234583	246992	266441	311988	450034	510367	370495
Ch 21	242752	194509	186734	195368	187223	169432	159432	157640	148696	137489
Ch 31	131892	128203	123661	118553	111806	109361	111076	109558	104654	101262
Ch 41	98791	96199	95395	94469	93286	92303	90567	86739	83029	80705
Ch 51	78085	77207	75847	73956	72126	70832	71104	71489	70149	67384
Ch 61	65980	67370	72864	77890	77803	70477	62095	57197	54213	53084
Ch 71	52486	50976	50886	49997	49953	50204	49831	50214	50470	49970
Ch 81	49122	46961	45163	43662	42504	41688	41247	40990	40322	39942
Ch 91	40005	39682	39680	39492	38437	38155	38099	38055	37434	36452
Ch 101	35863	34989	34194	33394	32326	32439	32340	31936	31864	31480
Ch 111	31212	30704	30135	30190	29028	28617	28049	27662	27098	26772
Ch 121	26382	26228	25806	25250	25287	25197	25236	25279	25658	26059
Ch 131	26270	26029	25298	24982	24579	24001	23889	23582	23485	23122
Ch 141	22883	22074	21428	20708	20451	20271	19748	19738	19255	18863
Ch 151	18568	18631	18473	18751	19432	19881	20151	20371	20278	19801
Ch 161	19057	18540	17873	17144	16613	16269	16168	15907	15487	15886
Ch 171	15417	15634	15650	15585	15579	15727	15677	15838	15640	15871
Ch 181	15482	15519	15301	15069	14616	14394	14428	14318	14013	13775
Ch 191	14152	13791	14161	14403	14759	15115	15544	16073	16152	16181
Ch 201	15678	15218	14821	14185	14002	13851	13578	13415	13255	13268
Ch 211	13594	14138	14419	15390	15775	16365	16425	15879	15137	14305
Ch 221	13583	13038	12832	12638	12367	12246	12275	11849	11662	11506
Ch 231	11235	10790	10651	10514	10322	10182	10016	10004	10358	10471
Ch 241	10639	11073	11100	10824	10661	10135	9523	9037	8651	8214
Ch 251	7585	7290	6928	6402	6023	5523	5298	5000	4780	4707
Ch 261	4427	4368	4252	4216	4020	3996	3776	3601	3495	3467
Ch 271	3237	3293	3148	3079	3020	2968	2892	2950	2939	2851
Ch 281	2850	2743	2624	2684	2611	2440	2374	2422	2367	2387
Ch 291	2316	2172	2209	2180	2132	2127	2002	2021	2054	2020
Ch 301	1980	1970	1918	1912	1793	1746	1837	1758	1713	1739
Ch 311	1652	1692	1706	1662	1569	1610	1527	1450	1417	1435
Ch 321	1373	1320	1195	1318	1291	1292	1255	1187	1160	1207
Ch 331	1139	1093	1119	1019	1018	1029	982	898	917	889
Ch 341	894	834	850	784	786	794	778	763	768	693
Ch 351	707	686	671	660	658	591	591	573	568	519
Ch 361	580	520	558	489	491	477	485	472	488	469
Ch 371	450	484	429	393	417	411	389	415	343	376
Ch 381	346	363	298	339	317	292	310	282	332	285
Ch 391	273	266	262	263	232	251	242	207	223	208
Ch 401	204	221	198	176	202	175	168	174	190	167
Ch 411	161	136	170	163	188	144	149	143	130	140
Ch 421	147	123	157	131	136	130	114	103	105	102
Ch 431	109	106	102	84	117	94	74	91	88	96
Ch 441	94	82	62	83	87	70	64	84	83	77
Ch 451	79	76	63	74	73	60	73	57	58	61
Ch 461	55	55	52	60	53	55	56	47	46	53
Ch 471	52	61	53	49	59	38	35	49	46	39
Ch 481	39	43	33	37	39	40	38	42	51	36
Ch 491	24	34	35	31	28	19	32	37	22	34
Ch 501	18	33	23	26	33	27	29	26	25	27

Sandpit calibration (Sand, 10%C): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	625	36854	171194	241056	280508	278135	236270	206566	188397
Ch 11	172854	159301	146768	137565	132864	130677	153788	287255	334259	195664
Ch 21	122826	102552	85360	81092	80189	76684	74566	72531	72558	71430
Ch 31	69806	68308	66530	64687	63342	61419	59911	58832	58212	56666
Ch 41	54456	52755	51594	50250	49421	48464	47037	45647	44132	42976
Ch 51	42144	39990	38520	36613	34673	32217	30694	29648	28492	27568
Ch 61	26753	26536	28234	29376	28407	24909	21154	18801	17917	17013
Ch 71	16330	16084	15569	15463	15553	15253	15344	16016	16576	16915
Ch 81	16064	14964	13539	12846	12437	12483	12524	12607	12269	12275
Ch 91	12087	12239	12175	12060	12124	11771	11451	11408	11229	10921
Ch 101	10793	10477	10268	9875	10009	10280	10508	10475	10461	10414
Ch 111	10066	9748	9427	9403	8965	8816	8671	8482	8374	8246
Ch 121	8285	8558	9045	9581	10170	10592	10299	9466	8720	7826
Ch 131	7348	7142	6935	6665	6465	6627	6539	6492	6469	6377
Ch 141	6346	6247	6124	6042	6091	6021	5937	5957	5951	5900
Ch 151	5854	5803	5780	5957	6227	6381	6567	6605	6282	6025
Ch 161	5745	5689	5486	5398	5316	5196	5041	5042	5050	5038
Ch 171	5452	5735	6216	6549	6747	6612	6171	5662	5164	4678
Ch 181	4325	4193	4081	4035	3942	3929	3913	3894	3827	3735
Ch 191	3728	3744	3656	3668	3700	3742	3885	3940	4019	3893
Ch 201	3912	3736	3636	3609	3566	3611	3387	3443	3330	3319
Ch 211	3233	3222	3385	3543	3702	3705	3713	3589	3352	3101
Ch 221	2930	2823	2766	2743	2650	2672	2706	2540	2307	2229
Ch 231	2096	1970	1969	1949	1967	1901	1889	1927	1941	1962
Ch 241	1963	1978	1966	1934	1828	1697	1565	1442	1363	1299
Ch 251	1230	1215	1161	1047	1070	943	888	786	688	667
Ch 261	572	565	490	575	537	552	533	607	588	624
Ch 271	594	537	530	507	458	365	386	290	324	266
Ch 281	271	251	243	215	217	185	167	181	172	167
Ch 291	163	164	143	182	186	188	199	198	195	195
Ch 301	183	180	149	130	122	103	99	74	74	91
Ch 311	78	74	66	78	66	58	80	64	62	71
Ch 321	65	55	57	42	42	51	38	44	39	49
Ch 331	33	38	18	40	33	16	24	30	31	21
Ch 341	15	35	18	16	22	17	23	25	21	22
Ch 351	31	22	20	29	25	27	24	18	18	21
Ch 361	22	15	11	18	17	17	17	16	18	23
Ch 371	16	13	16	16	22	19	10	15	9	7
Ch 381	16	16	6	12	8	17	4	7	11	6
Ch 391	8	7	5	8	6	8	6	4	8	11
Ch 401	9	12	5	7	9	9	6	5	9	5
Ch 411	7	4	9	10	9	6	12	8	4	7
Ch 421	3	9	7	10	5	5	8	8	12	11
Ch 431	6	2	4	8	2	11	4	11	7	3
Ch 441	11	10	10	10	7	4	5	3	6	6
Ch 451	4	7	4	7	1	8	7	4	7	7
Ch 461	7	7	9	6	9	6	7	8	8	6
Ch 471	3	5	8	5	8	3	4	4	5	6
Ch 481	0	3	2	5	6	9	3	6	4	5
Ch 491	8	6	4	3	5	5	6	6	7	4
Ch 501	6	9	7	6	3	8	3	6	6	5

APPENDIX B

Sandy soil (outside Bldg 830): "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	13754	247651	388985	375763	385357	350903	365504	367894	286096
Ch 11	258811	235161	217362	210536	221939	240314	279362	385401	438332	333690
Ch 21	220294	176243	170414	180155	173153	154598	145718	144920	137044	127729
Ch 31	122515	119337	115393	109680	103030	100879	101503	100661	97305	92729
Ch 41	90777	89307	87664	86935	86393	84966	82522	79811	77308	75261
Ch 51	72717	70743	68539	66315	65145	64246	64373	64846	63907	61126
Ch 61	59468	58587	59757	61129	60389	57470	54213	51734	49985	49511
Ch 71	47769	47644	47190	46675	46611	46503	46873	46877	47663	47515
Ch 81	45332	44133	42021	40975	39409	38981	37623	37719	37206	37431
Ch 91	37058	36982	37441	36893	36356	35813	35295	34720	34530	33689
Ch 101	32623	31894	30667	29744	29599	29627	29606	29546	28983	28731
Ch 111	28351	28075	27788	27188	26761	26313	25546	25263	24638	24472
Ch 121	24049	23530	23114	23059	22793	22497	22625	22629	23284	23352
Ch 131	23700	23465	23146	22698	22272	21551	21761	21429	20687	20320
Ch 141	19817	19392	18700	18218	17804	17870	17196	16947	16675	16499
Ch 151	16270	16127	15972	16193	16393	16511	16889	16845	16756	16143
Ch 161	15965	15219	14972	14513	14323	14105	13625	13800	13541	13522
Ch 171	13218	13366	13332	13491	13242	13176	13419	13325	13209	13326
Ch 181	13180	12951	12914	12716	12470	12536	12282	12315	12304	12208
Ch 191	12006	12091	12383	12261	12774	12977	13737	13898	13839	13743
Ch 201	13552	12891	12486	12312	12029	11649	11539	11553	11163	11250
Ch 211	11498	11816	12221	13006	13740	14041	13841	13477	12889	12018
Ch 221	11436	11026	10406	10383	10258	10140	9975	9792	9475	9430
Ch 231	9262	8982	8738	8710	8564	8399	8357	8309	8256	8516
Ch 241	8482	8782	8860	8854	8717	8234	7934	7564	7181	6715
Ch 251	6669	6164	5912	5436	4956	4782	4399	4246	4073	3933
Ch 261	3846	3557	3543	3412	3256	3313	3146	3054	3070	2980
Ch 271	2878	2780	2717	2672	2448	2570	2607	2534	2476	2372
Ch 281	2400	2359	2289	2245	2192	2171	2150	2097	1969	1929
Ch 291	1963	1877	1982	1967	1841	1922	1824	1859	1783	1641
Ch 301	1636	1637	1513	1621	1584	1553	1529	1446	1558	1377
Ch 311	1498	1381	1377	1366	1306	1336	1244	1219	1162	1204
Ch 321	1132	1070	1109	1071	1055	981	995	951	975	942
Ch 331	959	901	890	796	826	863	802	787	784	720
Ch 341	689	731	695	681	665	669	663	646	656	541
Ch 351	596	569	536	509	515	514	480	491	497	474
Ch 361	449	469	438	446	383	404	407	363	393	340
Ch 371	346	376	352	325	309	356	296	336	292	295
Ch 381	289	280	272	236	249	254	245	235	233	235
Ch 391	221	209	196	229	203	192	188	181	209	197
Ch 401	168	165	180	170	157	150	154	145	129	133
Ch 411	131	156	133	130	114	121	122	107	110	112
Ch 421	102	102	118	101	105	93	90	100	74	82
Ch 431	75	83	74	76	83	83	86	84	67	77
Ch 441	65	69	58	78	65	59	70	69	65	60
Ch 451	55	60	69	50	53	48	65	44	47	46
Ch 461	43	57	37	32	38	39	41	33	31	49
Ch 471	29	36	36	38	33	42	25	41	35	41
Ch 481	44	39	27	36	26	26	40	26	29	23
Ch 491	30	28	21	31	21	26	33	20	28	14

Ch 501	18	29	30	18	17	25	27	21	21	21

Sandy soil (outside Bldg 830): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	3811	78032	247734	279315	280709	265021	237018	215256	193526
Ch 11	178015	164080	151795	143224	139377	136735	153080	239162	272909	188956
Ch 21	127737	107184	91925	89235	87396	82659	79616	77491	76247	74812
Ch 31	72850	69983	67931	66449	63914	62252	61694	60512	58957	57422
Ch 41	54691	53395	52239	51042	49754	48404	47811	45891	44728	43917
Ch 51	42939	42080	40184	39027	35877	33453	32567	31612	30883	29478
Ch 61	28914	28629	28915	28780	27521	25323	23431	22192	22039	21773
Ch 71	21213	20104	19125	18233	18273	18188	18917	20807	23273	24255
Ch 81	22546	19409	16434	14899	13942	13944	13849	13599	13482	13219
Ch 91	13598	13202	13385	13238	13107	12815	12640	12627	12398	12030
Ch 101	11712	11403	10963	10909	10921	11112	11215	11156	11136	10949
Ch 111	10609	10313	10127	9905	9686	9544	9386	9100	8858	8884
Ch 121	8772	9041	9288	9741	10384	10391	10261	9523	8972	8344
Ch 131	7983	7667	7416	7325	7395	7214	7232	7199	7108	6968
Ch 141	6826	6665	6335	6460	6210	6253	6248	6119	6010	6078
Ch 151	5896	5991	5987	6319	6635	6672	6668	6690	6488	6207
Ch 161	5960	5742	5361	5417	5276	5188	5079	4977	4944	5183
Ch 171	5419	5737	6246	6434	6532	6333	5836	5414	5127	4611
Ch 181	4574	4280	4219	4145	4079	4056	4087	3884	4063	3987
Ch 191	3917	4041	3982	4069	4051	4210	4160	4193	4290	4265
Ch 201	4122	4001	3824	3842	3973	3832	3983	3939	3924	3806
Ch 211	3798	3952	3961	3939	4102	4101	4073	4082	3734	3417
Ch 221	3201	3189	3120	3165	3161	3365	3155	3020	2735	2545
Ch 231	2430	2343	2175	2113	2150	2131	2223	2222	2188	2167
Ch 241	2158	2050	2001	1909	1920	1798	1809	1715	1666	1747
Ch 251	1685	1625	1573	1572	1426	1386	1220	1100	1009	990
Ch 261	868	839	785	821	828	917	934	1003	1042	1026
Ch 271	996	858	784	709	601	515	468	471	439	393
Ch 281	398	356	371	353	329	277	318	291	297	315
Ch 291	277	268	274	290	257	301	294	285	291	297
Ch 301	300	264	257	234	211	187	196	205	160	174
Ch 311	181	174	164	161	200	141	148	152	130	159
Ch 321	127	143	130	121	137	133	116	123	112	126
Ch 331	98	97	86	102	73	78	86	74	65	82
Ch 341	72	59	63	70	73	72	64	68	67	60
Ch 351	65	61	65	45	57	49	48	53	48	58
Ch 361	41	42	55	39	43	50	38	36	46	44
Ch 371	24	40	33	36	33	41	27	34	26	23
Ch 381	30	36	18	24	26	29	17	30	23	31
Ch 391	27	16	17	21	20	20	16	19	24	21
Ch 401	15	21	17	24	16	19	21	22	6	14
Ch 411	10	5	9	18	11	21	13	18	13	16
Ch 421	19	13	12	17	18	15	16	12	11	12
Ch 431	9	11	13	9	11	17	9	8	12	9
Ch 441	11	11	13	8	9	4	6	10	13	12
Ch 451	11	13	9	18	8	8	13	6	11	8
Ch 461	12	15	8	11	7	5	11	9	8	12
Ch 471	8	2	6	9	8	7	9	6	7	7
Ch 481	11	6	12	6	6	6	5	7	10	3
Ch 491	6	6	3	5	6	4	3	7	8	11

Ch 501	4	8	8	4	8	5	7	9	9	5
Ch 511	6	11								

Pine Stand (with leaves): "Inelastic" gamma ray spectrum, Live time:1800s

Ch 1	0	0	10482	274113	572826	564627	494227	488323	463936	381414
Ch 11	346338	315488	290531	279197	287500	299420	337815	443556	489027	382831
Ch 21	260811	215728	210253	213455	200708	182561	175640	171254	160705	150933
Ch 31	145702	141175	135553	129309	123389	123044	122355	118676	113266	109384
Ch 41	106519	104583	102646	101745	101421	100100	97908	93672	89491	87067
Ch 51	84317	82733	80971	79680	77799	77421	77973	76881	74980	73021
Ch 61	73080	76489	83600	87106	82496	72678	65168	60980	58533	56928
Ch 71	56384	55003	54500	54341	54002	54526	55390	56834	57808	56666
Ch 81	54323	51518	49025	47430	45530	45084	44764	43989	43480	43549
Ch 91	43147	43271	43476	42826	42216	42066	41616	41749	41400	40110
Ch 101	38444	38071	36215	35877	35325	35199	35608	35617	34973	35124
Ch 111	34694	33943	33258	32398	31717	31096	30415	29983	29396	29058
Ch 121	28579	28289	27702	27572	27340	27551	27734	28520	28992	29488
Ch 131	29358	28428	27366	26988	26446	25796	25922	25121	24450	23845
Ch 141	23087	22723	21971	21638	21348	20750	20639	20066	19744	19583
Ch 151	19086	19320	19362	19746	20547	20468	20409	20385	19873	19320
Ch 161	18831	18211	17772	17300	17236	16470	16265	16386	16342	16119
Ch 171	16426	16470	16465	16412	16328	16309	16896	16630	16693	16486
Ch 181	16379	16083	15972	15592	15398	15231	15048	14909	14714	14958
Ch 191	15250	15364	15803	16460	17074	18036	18522	18509	18207	17568
Ch 201	17038	16271	15842	15415	15130	14610	14378	14537	14471	15198
Ch 211	15948	17151	18464	19152	19477	19305	18136	17125	15723	14750
Ch 221	13858	13610	13441	13382	13004	12703	12610	12506	12353	11956
Ch 231	11681	11522	11208	11080	10870	10942	10893	11231	11323	11410
Ch 241	11683	11519	11286	11211	10562	10180	9874	9663	9173	8765
Ch 251	8189	7652	7174	6628	6240	5883	5547	5294	5206	4994
Ch 261	4866	4636	4577	4385	4363	4113	4095	3848	3857	3795
Ch 271	3579	3452	3465	3402	3185	3404	3374	3248	3230	3071
Ch 281	3017	3075	2931	2950	2810	2670	2661	2586	2566	2641
Ch 291	2556	2550	2486	2452	2404	2363	2374	2234	2225	2173
Ch 301	2228	2184	2083	2104	2018	2121	2034	1960	1930	1976
Ch 311	1878	1940	1906	1772	1754	1744	1730	1629	1587	1544
Ch 321	1509	1565	1433	1437	1400	1372	1335	1363	1330	1309
Ch 331	1253	1202	1144	1079	1077	1101	1076	1047	948	1021
Ch 341	946	971	952	923	885	871	855	794	812	748
Ch 351	779	795	716	741	678	680	651	607	650	583
Ch 361	599	561	621	604	544	553	530	533	469	482
Ch 371	488	470	451	459	426	454	400	429	399	394
Ch 381	364	377	327	361	364	318	370	332	273	336
Ch 391	292	270	293	267	262	273	269	237	253	220
Ch 401	242	238	209	218	205	185	193	181	185	177
Ch 411	182	172	195	192	179	160	160	142	144	150
Ch 421	139	140	136	139	121	132	142	116	107	124
Ch 431	103	123	116	117	83	96	102	87	100	105
Ch 441	92	93	97	100	95	88	77	78	84	69
Ch 451	79	81	68	80	72	65	71	62	68	72
Ch 461	50	57	70	48	52	51	60	54	51	58
Ch 471	52	41	62	49	47	51	46	44	46	50
Ch 481	31	50	48	46	34	45	36	39	39	42

Ch 491	33	34	47	30	30	39	35	41	34	29
Ch 501	41	30	42	36	38	26	31	38	29	23
Ch 511	31	33								

Pine Stand (with leaves): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	4	4913	191773	418716	412985	373837	325013	293257	267916
Ch 11	245136	225211	207801	195067	183603	177768	198341	309201	339050	232082
Ch 21	157789	132081	111808	108099	107133	101005	96999	94667	93036	91737
Ch 31	88825	85502	83614	82149	78436	76138	74822	73727	71267	69288
Ch 41	66848	65103	64105	62804	61568	61089	59259	57071	55817	55806
Ch 51	54158	52050	49906	47192	44709	42374	41318	40268	39631	38574
Ch 61	38807	41504	44807	45724	41469	36056	31216	29563	28114	26747
Ch 71	25556	24691	24536	24194	24757	25918	30479	39437	47653	47899
Ch 81	39222	28898	21502	18369	17011	16761	16590	16476	16218	16232
Ch 91	16053	16292	16421	16164	15617	15358	14994	14969	14497	14454
Ch 101	13527	13399	13082	13094	13495	13654	14136	14419	13972	13214
Ch 111	13121	12627	12153	11803	11626	11583	11060	10709	10597	10710
Ch 121	10845	11520	12577	14122	14764	14537	13670	12025	10741	9692
Ch 131	9032	8540	8428	8182	8205	8307	8339	8544	7936	7890
Ch 141	7799	7794	7557	7473	7347	7418	7266	7214	7283	7308
Ch 151	7306	7316	7485	7964	8401	8566	8562	8181	7743	7376
Ch 161	7054	6923	6823	6549	6354	6130	6130	6234	6287	6868
Ch 171	7758	8376	9197	9210	8911	8091	7068	6354	5694	5221
Ch 181	5103	4930	4747	4653	4606	4567	4608	4490	4613	4540
Ch 191	4590	4465	4511	4568	4706	4929	4918	4883	4948	4785
Ch 201	4623	4448	4471	4434	4528	4487	4563	4414	4455	4348
Ch 211	4497	4591	4663	4957	4966	4877	4413	4339	3940	3677
Ch 221	3693	3601	3658	3755	3598	3458	3064	2887	2645	2564
Ch 231	2496	2505	2570	2629	2555	2748	2745	2734	2573	2361
Ch 241	2330	2197	1989	1952	1818	2057	2079	2074	2221	2259
Ch 251	2269	2336	2151	1995	1736	1575	1412	1185	1095	988
Ch 261	939	954	1037	1200	1327	1527	1547	1601	1548	1439
Ch 271	1292	1011	881	700	621	522	485	407	358	358
Ch 281	295	306	311	276	232	233	203	213	215	186
Ch 291	241	236	278	254	286	280	277	264	253	243
Ch 301	204	183	173	142	151	164	157	141	157	140
Ch 311	128	118	112	101	108	85	97	105	85	100
Ch 321	88	107	99	118	94	123	89	73	80	57
Ch 331	52	45	51	33	32	32	33	38	25	25
Ch 341	33	34	28	36	32	39	34	30	21	36
Ch 351	27	32	20	30	24	27	28	20	31	19
Ch 361	34	31	18	29	25	28	24	21	23	18
Ch 371	19	27	20	18	14	19	11	15	9	17
Ch 381	7	10	18	14	8	12	15	8	19	9
Ch 391	5	7	10	9	10	5	10	6	9	8
Ch 401	16	5	11	7	7	11	3	8	8	6
Ch 411	9	9	10	9	11	8	9	2	7	3
Ch 421	12	10	8	9	6	9	8	12	9	10
Ch 431	3	8	6	6	8	12	8	11	6	3
Ch 441	9	8	7	5	7	5	4	7	11	9
Ch 451	4	9	5	10	1	8	3	1	4	8
Ch 461	7	7	6	5	6	3	9	7	4	3
Ch 471	5	8	2	2	9	9	7	2	4	4

Ch 481	7	4	3	6	3	5	3	6	6	5
Ch 491	4	5	12	4	4	2	7	6	4	10
Ch 501	4	3	2	6	4	8	3	6	6	6
Ch 511	7	5								

Pine Stand (without leaves): "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	4	12723	267562	535969	533017	469127	465452	447482	364627
Ch 11	332355	301947	278108	267389	274656	289881	326688	430773	478943	376258
Ch 21	253847	208304	202465	207985	196650	177399	169724	166926	157222	147072
Ch 31	142019	137328	132306	125745	119459	118697	119429	115287	110509	106563
Ch 41	104284	102532	99748	98697	98542	96979	95044	91392	87386	84440
Ch 51	82419	81545	78712	77538	76180	74853	75379	74940	72865	70722
Ch 61	69720	73504	78705	83506	79679	71331	63573	59616	57326	55660
Ch 71	54296	54075	53220	52963	52561	52906	53603	54705	55263	55106
Ch 81	52965	49955	47598	45558	44450	43913	42788	42611	42423	41968
Ch 91	41850	41988	41902	41555	40818	40695	40818	40438	39913	38831
Ch 101	37716	36496	34951	34564	33954	34255	34263	34368	33843	33382
Ch 111	33105	32646	32466	31791	30443	30195	28955	28664	28498	27340
Ch 121	27718	27361	26566	26650	26147	26096	26643	27294	27508	28080
Ch 131	28035	27217	26510	26155	25282	25211	24678	23900	23780	22985
Ch 141	22333	21620	21072	20600	20469	19770	19535	19562	19038	18984
Ch 151	18671	18620	18672	18744	19488	19515	19551	19451	19304	18859
Ch 161	18228	17410	17209	16716	16358	16253	16000	15774	15649	15651
Ch 171	15811	15693	15626	15438	15799	15813	16250	16054	15867	15922
Ch 181	15471	15237	14883	15038	14661	14362	14318	14277	14546	14099
Ch 191	14082	14233	14624	15247	16082	16906	17207	17393	17272	16707
Ch 201	16187	15673	14947	14601	14331	13996	13786	13682	13614	14179
Ch 211	14908	15896	17062	17891	18337	18354	17310	15950	15107	14274
Ch 221	13485	13119	12765	12626	12527	12264	12249	11746	11608	11504
Ch 231	11366	10932	10622	10512	10388	10290	10312	10415	10721	11010
Ch 241	11097	10924	10865	10693	10219	9932	9296	9149	8693	8542
Ch 251	7894	7322	6803	6270	5927	5683	5331	5074	4928	4700
Ch 261	4589	4421	4453	4248	4056	4014	3944	3762	3708	3571
Ch 271	3497	3498	3362	3221	3185	3222	3109	3083	3062	3009
Ch 281	2863	2809	2846	2639	2732	2657	2667	2542	2447	2473
Ch 291	2439	2448	2385	2442	2185	2305	2261	2214	2170	2022
Ch 301	2107	2118	1989	2073	2016	1940	2004	1927	1953	1833
Ch 311	1843	1758	1699	1775	1714	1586	1653	1612	1531	1515
Ch 321	1445	1414	1339	1376	1315	1215	1253	1243	1285	1240
Ch 331	1189	1178	1147	1112	1095	1034	930	970	968	969
Ch 341	934	884	875	864	801	792	835	791	762	725
Ch 351	757	705	669	619	660	629	624	613	582	559
Ch 361	579	501	548	536	505	513	497	517	460	433
Ch 371	466	434	465	422	428	426	426	402	381	403
Ch 381	367	338	359	320	296	318	292	328	311	284
Ch 391	297	310	270	267	256	241	250	230	251	222
Ch 401	215	220	227	198	185	179	174	157	151	156
Ch 411	187	188	158	168	146	147	146	156	118	135
Ch 421	113	128	143	114	112	130	128	103	121	114
Ch 431	113	89	104	102	98	94	109	104	89	92
Ch 441	80	92	92	90	91	77	70	89	83	72
Ch 451	77	93	70	66	67	74	71	64	70	67
Ch 461	52	52	53	55	45	47	48	66	50	58

Ch 471	45	46	44	45	48	57	35	56	45	38
Ch 481	40	47	45	32	40	35	43	38	43	43
Ch 491	29	35	24	34	37	32	35	23	40	30
Ch 501	37	32	32	27	21	34	14	23	29	24
Ch 511	22	30								

Pine Stand (without leaves): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	5	6069	193475	405520	399855	364194	317034	285139	262577
Ch 11	239796	220318	203771	190576	181174	175561	196471	306936	334918	229626
Ch 21	156752	130256	109969	106196	104896	98591	95168	92453	90868	89401
Ch 31	86158	83786	81476	78996	76572	74214	72209	70893	69040	67736
Ch 41	65355	63840	62599	60736	59478	59378	58099	55542	54998	54077
Ch 51	52588	50601	48783	45932	43528	41064	40055	39287	38450	37272
Ch 61	37602	39744	42871	43293	39974	34330	30229	28103	26849	26030
Ch 71	25119	24010	23712	23542	24048	25062	29375	37073	44946	45374
Ch 81	37583	28154	21265	17700	16794	16466	16397	16480	15927	15963
Ch 91	15941	16160	16080	15835	15686	15086	14720	14391	14179	13846
Ch 101	13440	13132	12850	12901	13159	13435	13797	14134	13955	13120
Ch 111	12456	12220	11884	11655	11370	11101	10926	10589	10677	10354
Ch 121	10676	11312	12344	13354	14033	13988	13126	11458	10304	9470
Ch 131	8881	8464	8178	8066	7995	8065	8173	7907	8008	7821
Ch 141	7739	7582	7212	7331	7116	7238	7289	7002	6859	7062
Ch 151	6916	6997	7171	7695	8035	8214	8168	8001	7465	7101
Ch 161	6968	6811	6556	6283	6184	6102	5921	5796	6186	6724
Ch 171	7258	8294	8815	8978	8546	7950	6985	6186	5689	5226
Ch 181	4994	4683	4597	4585	4511	4407	4499	4326	4461	4485
Ch 191	4253	4421	4360	4565	4548	4614	4578	4761	4721	4541
Ch 201	4410	4322	4288	4333	4313	4369	4255	4376	4240	4137
Ch 211	4260	4333	4543	4485	4609	4555	4354	4070	3771	3651
Ch 221	3498	3510	3544	3465	3378	3113	3038	2795	2633	2472
Ch 231	2424	2487	2379	2587	2547	2630	2631	2587	2579	2308
Ch 241	2154	2087	2047	1902	1879	1860	1931	2049	2133	2172
Ch 251	2259	2115	2055	1871	1668	1512	1304	1134	1058	936
Ch 261	912	968	1063	1152	1305	1470	1518	1526	1517	1328
Ch 271	1230	1067	849	696	577	449	419	373	365	344
Ch 281	300	265	258	236	241	233	242	206	199	189
Ch 291	207	250	236	268	237	270	280	235	235	211
Ch 301	195	181	170	164	149	145	143	143	133	137
Ch 311	121	108	113	120	93	117	115	104	103	108
Ch 321	124	94	103	106	87	84	71	75	57	60
Ch 331	54	46	46	35	40	36	35	36	36	34
Ch 341	24	27	36	28	31	34	27	24	27	27
Ch 351	34	31	23	28	36	27	23	17	22	23
Ch 361	20	29	24	18	17	19	21	15	26	23
Ch 371	24	26	14	24	21	21	24	16	16	15
Ch 381	12	8	7	15	22	11	7	13	10	12
Ch 391	11	7	9	12	7	10	7	5	9	9
Ch 401	6	8	6	8	8	16	5	4	10	6
Ch 411	5	7	9	10	13	8	11	10	9	5
Ch 421	12	7	10	8	4	10	5	8	5	6
Ch 431	4	10	5	4	12	10	3	8	7	4
Ch 441	6	7	8	9	9	7	4	12	4	12
Ch 451	7	10	8	4	8	3	6	10	8	8

Ch 461	9	6	8	6	9	4	5	9	6	6
Ch 471	7	3	11	10	10	3	4	3	1	4
Ch 481	6	6	9	2	5	3	7	5	8	2
Ch 491	5	1	3	7	10	6	4	4	4	1
Ch 501	4	2	7	1	1	9	3	3	7	7
Ch 511	4	3								

Sand Patch: "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	1879	89872	228839	294036	310358	279444	281280	278672	215376
Ch 11	196839	177058	163047	156888	165226	177788	205822	289438	329227	241450
Ch 21	154701	122228	119596	126931	122217	108365	102013	101419	95706	89082
Ch 31	85541	83672	80406	76335	72335	71397	71475	70944	67356	65193
Ch 41	63550	61905	61204	60359	59969	59720	58244	55681	53344	50534
Ch 51	49920	49036	47900	46531	45449	45159	45122	44830	44550	42672
Ch 61	42055	42634	45657	48559	48107	43858	38748	35095	33738	32401
Ch 71	32016	31741	31249	31019	31035	31046	31426	31952	32584	32514
Ch 81	31132	29728	28336	27193	26186	25360	25054	24842	24633	24482
Ch 91	24481	24511	24595	24131	23815	23341	22950	22875	22821	22254
Ch 101	21505	20888	20218	19774	19488	19324	19213	19564	19084	19125
Ch 111	18636	18224	17892	17673	17255	16949	16569	16337	15798	15643
Ch 121	15364	15177	15002	15010	14587	14804	14684	14859	15239	15157
Ch 131	15131	15094	14675	14479	14071	13730	13577	13104	13035	12778
Ch 141	12496	12133	11918	11708	11259	11369	10975	10928	10745	10478
Ch 151	10211	10440	10242	10266	10557	10609	10688	10852	10736	10478
Ch 161	10220	9851	9691	9456	9344	9030	9099	8855	8755	8713
Ch 171	8726	8934	8913	8893	8739	8893	8782	8796	8898	8836
Ch 181	8659	8693	8304	8392	8140	7997	7924	7879	7793	7856
Ch 191	7788	7762	7864	7954	8101	8456	8707	9044	9106	9074
Ch 201	8817	8542	8015	7910	7698	7531	7467	7329	7221	7303
Ch 211	7273	7880	8072	8586	9029	9167	9208	8943	8294	7824
Ch 221	7416	7085	6743	6653	6566	6601	6551	6316	6106	6044
Ch 231	5900	5834	5724	5698	5548	5288	5314	5459	5328	5615
Ch 241	5740	5833	5795	5749	5753	5407	4970	4857	4610	4332
Ch 251	4051	4010	3667	3298	3217	2980	2794	2686	2502	2395
Ch 261	2321	2259	2294	2133	2020	2110	1940	1927	1907	1852
Ch 271	1755	1722	1681	1691	1680	1617	1604	1517	1553	1549
Ch 281	1471	1458	1413	1345	1327	1322	1294	1258	1172	1285
Ch 291	1218	1171	1178	1217	1192	1138	1069	1123	1106	1061
Ch 301	1003	1005	969	990	977	985	862	949	951	907
Ch 311	906	904	922	871	812	788	764	767	785	747
Ch 321	706	650	681	713	665	650	648	590	605	615
Ch 331	595	542	541	542	533	456	448	494	484	425
Ch 341	433	416	428	394	434	339	441	396	341	365
Ch 351	325	339	334	303	310	303	312	269	309	295
Ch 361	268	244	268	251	225	243	227	247	228	217
Ch 371	214	195	196	181	199	169	194	199	175	174
Ch 381	150	154	170	163	148	157	138	130	122	104
Ch 391	114	98	109	104	80	105	77	94	95	87
Ch 401	91	94	85	75	77	65	75	75	81	63
Ch 411	74	60	62	56	68	60	67	58	67	51
Ch 421	57	41	40	45	39	37	52	47	40	44
Ch 431	35	35	41	45	32	35	40	30	30	40
Ch 441	27	29	28	29	32	36	34	27	24	31

Ch 451	29	31	27	23	28	21	24	19	28	17
Ch 461	19	24	24	24	21	29	22	27	17	22
Ch 471	16	18	23	17	21	25	13	23	15	15
Ch 481	19	9	9	18	11	16	18	12	11	14
Ch 491	18	13	18	16	8	10	15	12	13	15
Ch 501	14	14	12	14	14	14	9	13	11	14
Ch 511	11	7								

Sand Patch: Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	1530	50618	206040	271800	280990	260011	231865	213385	194186
Ch 11	178636	165967	152896	145191	140846	137985	156051	245901	279642	192326
Ch 21	129688	106789	91514	88608	86763	80808	78828	76871	74692	73406
Ch 31	71692	68466	67512	65561	63349	62030	60060	59338	57483	56106
Ch 41	53893	52554	51358	50498	49311	49016	47610	46406	44778	43957
Ch 51	43155	41873	40360	38405	36518	34192	32862	32302	31535	30347
Ch 61	30304	30945	33116	34172	32339	28416	25456	23036	22015	20984
Ch 71	20372	20144	20341	20050	20284	20318	20987	22847	25423	26044
Ch 81	23468	20150	17493	16095	15616	15396	15122	15205	15014	14841
Ch 91	15035	15065	14965	15166	14709	14320	13961	13778	13505	13193
Ch 101	12866	12329	12224	11975	12160	12209	12485	12817	12539	11979
Ch 111	11769	11195	11052	11022	10647	10572	10190	9850	9665	9618
Ch 121	9615	9969	10514	11318	12130	11963	11663	10705	9585	8792
Ch 131	8366	8076	7955	7627	7604	7594	7535	7511	7341	7217
Ch 141	7183	6939	6909	6655	6608	6610	6686	6510	6431	6394
Ch 151	6520	6510	6522	6752	6939	7216	7319	7040	6741	6718
Ch 161	6321	6034	5836	5749	5741	5593	5428	5373	5704	5801
Ch 171	6234	6852	7276	7426	7297	6977	6347	5632	5169	4991
Ch 181	4598	4384	4248	4218	4215	4079	4165	4007	4062	3970
Ch 191	3915	3838	3894	3958	3959	4074	4296	4085	4163	4200
Ch 201	3926	3871	3963	3847	3789	3771	3753	3761	3538	3616
Ch 211	3550	3754	3853	3989	4017	3855	3802	3720	3560	3142
Ch 221	3209	3077	3040	3098	3038	2898	2859	2531	2459	2268
Ch 231	2216	2153	2173	2246	2194	2221	2274	2230	2326	2154
Ch 241	2180	2081	2004	1962	1838	1785	1782	1706	1788	1674
Ch 251	1672	1648	1648	1508	1387	1289	1064	1002	914	873
Ch 261	767	784	784	899	888	934	1043	1051	1041	893
Ch 271	883	826	720	625	545	479	497	432	487	413
Ch 281	352	362	343	329	304	307	288	313	262	253
Ch 291	274	269	302	310	306	312	312	327	288	277
Ch 301	242	249	216	217	196	189	203	180	182	206
Ch 311	158	147	178	167	161	131	144	118	145	132
Ch 321	158	147	178	167	161	131	144	118	145	132
Ch 331	83	97	80	99	82	69	77	75	68	90
Ch 341	73	52	48	51	64	51	60	69	50	47
Ch 351	52	47	46	38	50	52	51	47	48	40
Ch 361	34	30	37	34	43	30	48	35	27	35
Ch 371	35	35	29	26	23	31	26	34	29	32
Ch 381	26	26	25	24	21	20	28	21	21	21
Ch 391	9	18	20	21	22	18	24	14	15	18
Ch 401	14	17	17	16	10	17	14	10	11	15
Ch 411	14	14	7	12	13	8	12	9	6	15
Ch 421	14	12	14	12	11	13	17	10	10	8
Ch 431	19	9	8	10	11	8	11	11	11	12

Ch 441	4	12	5	9	6	9	6	9	6	5
Ch 451	8	4	10	7	6	6	12	10	4	8
Ch 461	6	7	10	6	5	13	8	7	9	8
Ch 471	5	2	2	8	7	8	9	8	6	7
Ch 481	6	7	14	6	6	7	2	8	7	7
Ch 491	6	4	5	6	11	7	6	5	2	8
Ch 501	5	3	8	9	5	10	10	4	5	6
Ch 511	4	3								

Oak Forest (without leaves): "Inelastic" gamma ray spectrum, Live time: 1800s

Ch 1	0	5622	144071	427636	528025	505196	442937	441289	432472	348626
Ch 11	317907	288532	266512	255529	264052	277844	310089	389501	444182	371499
Ch 21	253478	203422	196070	202882	193716	175238	165862	163600	155171	145005
Ch 31	140218	136735	131410	124137	117555	115683	116254	113458	108907	104478
Ch 41	102240	99838	98405	97977	97746	96282	94066	90124	86322	82319
Ch 51	80933	78939	77442	75578	74215	72837	73298	73376	71967	69792
Ch 61	68341	70765	75467	80241	78292	70803	63796	58240	56155	54688
Ch 71	53805	53208	52516	51789	51709	51872	52619	53969	55191	55409
Ch 81	53455	50049	46748	45401	43856	43142	42123	41824	41506	40959
Ch 91	41343	40701	41126	40784	40419	40092	40126	39452	39002	38181
Ch 101	36686	35775	34923	33809	33139	33031	33663	33173	32757	32807
Ch 111	31862	31881	31114	30417	29721	29073	28310	27920	27312	27215
Ch 121	26619	26132	25821	25293	25272	25304	25295	25493	26194	26675
Ch 131	26669	26590	25494	25148	24514	24255	23819	23301	22645	22032
Ch 141	21585	20509	20266	20117	19315	19349	19114	18681	18097	17989
Ch 151	17610	17456	17342	17962	18015	18522	18644	18684	18007	17826
Ch 161	17249	16646	16262	15989	15725	15506	15131	14889	14860	14685
Ch 171	14734	14819	14889	14921	14903	15030	14938	14954	14902	14841
Ch 181	14759	14665	14303	14077	14028	13731	13661	13307	13490	13347
Ch 191	13234	13293	13623	14309	14854	15351	15985	16302	16323	15979
Ch 201	15498	15018	14322	13855	13516	13180	13002	12919	12990	12950
Ch 211	13404	14346	15153	16203	17064	17197	16824	16103	14549	13720
Ch 221	12830	12193	11853	11697	11576	11292	11375	10956	10959	10670
Ch 231	10679	10519	10124	9964	9782	9566	9541	9428	9675	9784
Ch 241	10064	9922	10237	9869	9810	9266	9051	8701	8484	8103
Ch 251	7753	7317	6835	6372	5880	5656	5232	5050	4913	4703
Ch 261	4622	4442	4212	4099	4062	3970	3857	3848	3682	3538
Ch 271	3437	3333	3223	3199	3175	3129	3073	3059	2932	2962
Ch 281	2931	2867	2741	2667	2575	2539	2449	2394	2451	2385
Ch 291	2422	2315	2224	2277	2155	2262	2171	2173	2073	2112
Ch 301	1990	2004	1950	1887	1889	1815	1827	1847	1816	1739
Ch 311	1739	1676	1663	1584	1626	1539	1629	1513	1437	1420
Ch 321	1359	1306	1316	1312	1270	1254	1272	1222	1144	1209
Ch 331	1147	1075	1083	1006	1043	1008	957	948	865	962
Ch 341	837	887	795	786	796	774	784	758	710	758
Ch 351	687	694	662	646	629	592	596	568	564	598
Ch 361	549	555	499	548	517	500	500	502	496	432
Ch 371	458	424	400	396	395	390	393	365	369	361
Ch 381	325	340	356	338	300	284	274	282	296	234
Ch 391	249	249	231	232	224	221	239	191	204	215
Ch 401	216	226	168	196	171	203	193	184	198	158
Ch 411	165	142	164	145	150	135	131	131	113	150
Ch 421	119	140	141	111	105	114	115	96	99	117

Ch 431	104	101	105	101	83	84	87	83	84	70
Ch 441	85	84	64	82	66	82	77	69	73	72
Ch 451	64	89	76	83	47	54	63	70	71	63
Ch 461	54	55	51	52	63	42	58	42	54	40
Ch 471	47	46	47	48	41	51	41	45	40	54
Ch 481	47	49	52	40	32	33	37	34	34	43
Ch 491	30	32	30	31	21	35	24	43	33	23
Ch 501	33	36	28	29	31	21	24	31	32	18
Ch 511	36	32								

Oak Forest (without leaves): Prompt gamma ray spectrum, Live time: 1800s

Ch 1	0	1624	62306	318026	407720	398449	365571	314365	284290	261669
Ch 11	239294	221380	205181	191689	182318	176516	190010	284102	336648	250463
Ch 21	167281	135890	113588	107442	105780	100908	97401	94643	92174	91199
Ch 31	88965	85059	83575	80851	78162	75438	73878	71881	70575	69346
Ch 41	66589	65154	63889	62679	61523	60876	59327	58052	56677	56302
Ch 51	55080	52737	50908	48754	46147	44092	42568	41827	41084	40067
Ch 61	40292	42372	44920	45808	43736	38995	34351	31761	30706	29747
Ch 71	28337	27305	26753	26955	26719	27545	31689	40175	51386	55676
Ch 81	49349	37226	26765	21099	18962	18202	18030	18106	17602	17515
Ch 91	17429	17454	17425	17357	17051	16713	16317	16130	15848	15531
Ch 101	15124	14362	14272	14094	14245	14579	14976	15137	15007	14562
Ch 111	13856	13641	12901	12983	12519	12478	11844	11668	11474	11301
Ch 121	11440	11699	12728	13912	14883	15118	14880	13441	11805	10706
Ch 131	9936	9313	9086	8895	8621	8716	8649	8813	8784	8579
Ch 141	8170	8223	8105	8005	8095	7938	7906	7637	7940	7628
Ch 151	7498	7655	7805	8019	8338	8846	8890	8546	8549	8081
Ch 161	7688	7234	7106	6990	6905	6732	6332	6281	6595	6788
Ch 171	7483	8048	8894	9410	9467	9048	8284	7345	6403	5777
Ch 181	5616	5204	5072	5001	4868	4821	4850	4670	4870	4722
Ch 191	4777	4640	4637	4611	4709	4841	4805	5057	4875	4937
Ch 201	4799	4684	4571	4533	4614	4600	4526	4400	4443	4457
Ch 211	4382	4431	4429	4534	4627	4574	4507	4303	4036	3921
Ch 221	3666	3695	3743	3826	3641	3506	3371	3134	2970	2904
Ch 231	2654	2479	2669	2568	2633	2732	2728	2766	2781	2643
Ch 241	2483	2362	2281	2225	2190	2004	2040	2163	2213	2302
Ch 251	2306	2310	2322	2104	1978	1844	1591	1417	1239	1158
Ch 261	1018	1003	1072	1079	1307	1377	1475	1603	1627	1605
Ch 271	1554	1300	1105	926	786	622	499	469	398	352
Ch 281	345	336	276	273	269	251	211	218	195	223
Ch 291	232	211	247	243	233	281	280	298	260	235
Ch 301	236	192	177	184	147	151	140	128	126	108
Ch 311	139	126	111	106	106	117	84	91	96	91
Ch 321	94	97	76	104	106	90	69	77	79	57
Ch 331	58	40	42	42	36	26	28	31	23	27
Ch 341	29	23	34	26	26	30	24	20	22	22
Ch 351	26	23	30	29	28	16	21	21	21	20
Ch 361	19	19	21	17	24	21	19	23	19	19
Ch 371	22	24	21	17	16	16	22	10	20	8
Ch 381	11	15	12	9	10	15	5	15	9	7
Ch 391	4	16	10	9	12	8	5	10	10	9
Ch 401	11	6	6	13	9	10	13	5	5	8
Ch 411	7	5	10	9	9	6	7	9	4	12

Ch 421	1	9	11	6	6	6	6	8	4	2
Ch 431	10	10	5	8	11	5	12	11	4	3
Ch 441	8	7	4	10	6	3	8	6	2	5
Ch 451	6	2	4	6	7	5	6	4	2	9
Ch 461	3	4	5	7	8	8	1	3	6	8
Ch 471	4	8	7	1	6	5	5	5	6	9
Ch 481	5	7	1	6	6	4	7	4	4	5
Ch 491	1	3	6	6	3	4	5	5	4	5
Ch 501	7	6	8	6	10	4	4	3	7	4
Ch 511	5	4								

Pine Stand (with leaves): "Inelastic" gamma ray spectrum, Live time: 3600s

Ch 1	0	545	124443	847175	1236908	1203626	1063859	1043652	1007137	821341
Ch 11	746546	680192	627114	599270	612226	640035	713582	936098	1058893	850140
Ch 21	579981	468801	449212	456390	434130	393419	371759	366186	344704	322694
Ch 31	311334	302213	290954	275492	263176	260949	259551	253226	242582	233819
Ch 41	227591	223289	218409	216434	215586	214068	209417	200858	192957	185133
Ch 51	181579	177927	174032	168843	166684	164241	164004	164869	161041	155309
Ch 61	152917	159469	174584	185970	180901	163065	143384	131666	125985	122648
Ch 71	119870	118792	116561	115477	114614	115421	116716	119160	121211	121382
Ch 81	117196	111740	105874	101683	98795	96077	94872	94126	93245	92223
Ch 91	92456	92299	92106	91442	90519	89877	89656	89308	88678	86724
Ch 101	84101	81814	78927	77112	75692	75361	75621	75435	75040	74590
Ch 111	73971	72873	71737	70421	68447	66795	65366	64361	63170	62484
Ch 121	61822	60494	59933	58671	58383	58260	58191	60330	61349	62205
Ch 131	62415	61924	60255	58590	57240	56441	55733	54793	53323	52094
Ch 141	50315	49267	47965	46692	45848	45060	44450	43893	42883	42324
Ch 151	41554	41102	41330	41527	42501	42765	43615	43562	43002	42343
Ch 161	40927	39905	38986	37739	37092	36462	35900	35180	35129	35172
Ch 171	35098	35013	35075	35304	35461	35426	35523	35541	35673	36019
Ch 181	35663	34728	34458	33622	33190	32686	32643	32456	31994	32161
Ch 191	31923	32159	32928	33652	35595	36639	38544	39432	39514	38590
Ch 201	37396	36058	34949	33759	32693	31670	31485	30911	31020	31578
Ch 211	32754	34568	36543	39105	40874	41261	40569	38778	36280	33965
Ch 221	32019	30103	29445	28907	28881	28136	27626	27129	27074	26478
Ch 231	26301	25465	25062	24251	24180	23786	23228	23559	23808	24534
Ch 241	24837	25276	25073	24618	24012	23285	22337	21691	20710	19765
Ch 251	18870	17875	16765	15398	14414	13546	12663	12141	11716	11277
Ch 261	11007	10798	10277	10016	9633	9561	9228	8962	8573	8462
Ch 271	8214	7832	7778	7666	7441	7375	7281	7114	7015	7012
Ch 281	6844	6789	6477	6257	6245	5976	5857	5849	5585	5705
Ch 291	5549	5601	5393	5394	5260	5341	5147	5141	5052	4993
Ch 301	4840	4804	4713	4592	4656	4492	4428	4487	4398	4178
Ch 311	4267	4185	4099	4003	3956	3917	3816	3716	3653	3533
Ch 321	3504	3376	3205	3274	3268	3180	3025	2933	2860	2850
Ch 331	2833	2794	2750	2693	2561	2496	2416	2377	2325	2310
Ch 341	2201	2175	2066	2075	2042	1950	1929	1951	1808	1810
Ch 351	1744	1591	1725	1709	1552	1553	1526	1384	1431	1308
Ch 361	1422	1415	1340	1279	1251	1268	1160	1199	1131	1174
Ch 371	1157	1039	1080	1106	1032	996	957	956	957	913
Ch 381	862	878	858	841	777	818	774	735	712	749
Ch 391	683	617	659	623	566	627	620	570	535	522
Ch 401	571	532	484	482	470	503	450	428	429	397

Ch 411	426	390	394	358	392	370	333	330	371	293
Ch 421	342	348	320	305	286	284	279	323	314	282
Ch 431	258	274	256	256	238	247	254	247	213	214
Ch 441	201	207	226	182	199	210	188	174	183	192
Ch 451	166	160	194	154	164	166	179	181	166	152
Ch 461	135	128	144	128	132	137	128	138	111	99
Ch 471	133	134	129	116	124	102	124	100	102	97
Ch 481	102	101	108	112	104	107	93	84	97	86
Ch 491	94	94	95	63	74	74	75	77	54	79
Ch 501	76	76	62	66	69	53	77	77	66	51
Ch 511	60	62								

ine Stand (with leaves): Prompt gamma ray spectrum, Live time:3600s

Ch 1	0	113	33817	496318	919474	905161	828117	726237	653503	599703
Ch 11	547705	504309	468167	436936	415483	404378	454668	711926	782264	532598
Ch 21	363914	301134	253686	244969	240307	228636	219430	215629	212167	208066
Ch 31	201262	194779	189670	184758	179275	173973	169588	166329	162805	157880
Ch 41	152652	149229	146062	143636	140815	138362	135237	131400	127679	126431
Ch 51	122916	117628	113024	107121	100797	96471	93274	91538	89317	86494
Ch 61	87634	93749	101380	103739	94963	80758	70612	64952	62101	59999
Ch 71	57266	55094	54393	54426	55161	57609	66424	83825	101188	101431
Ch 81	85425	63881	48858	41260	38681	38106	38042	37404	36805	36714
Ch 91	36931	37099	37002	36852	35514	34738	34489	33721	32763	32221
Ch 101	31303	29963	29816	29720	29813	30901	32029	32724	31514	30364
Ch 111	29352	28061	27430	26998	26861	25797	25095	24303	23999	23960
Ch 121	24418	26183	28520	31441	32592	32621	30284	27203	24005	21940
Ch 131	20664	19953	19081	18970	18564	18340	18612	18670	18344	17991
Ch 141	17530	17225	16996	16728	16907	16864	16656	16584	16450	16166
Ch 151	16224	16321	17001	17842	18377	19059	18969	18308	17349	16741
Ch 161	16036	15664	15321	14796	14506	14068	14037	13504	14424	15397
Ch 171	16968	18659	20111	20766	20155	18168	16273	14519	13015	11907
Ch 181	11658	11239	10850	10689	10470	10639	10267	10449	10301	10114
Ch 191	10299	10308	10410	10379	10713	11038	11340	11447	11184	11026
Ch 201	10814	10202	10169	10117	10147	10235	10041	10051	9893	9681
Ch 211	9880	10320	10637	11231	11207	11063	10437	9720	8869	8418
Ch 221	7979	7993	7996	8089	7791	7436	7041	6443	6051	5824
Ch 231	5536	5599	5725	5829	5893	6052	6050	5811	5777	5462
Ch 241	5144	5008	4760	4657	4388	4351	4574	4813	4891	5022
Ch 251	5123	5023	4753	4430	3938	3449	3190	2819	2423	2230
Ch 261	2167	2239	2329	2666	2898	3258	3507	3559	3540	3112
Ch 271	2675	2378	2016	1603	1433	1224	1013	963	877	789
Ch 281	715	736	659	605	553	540	468	507	468	491
Ch 291	510	555	581	605	665	668	656	584	570	481
Ch 301	495	417	381	347	378	352	349	359	349	331
Ch 311	304	274	297	269	240	248	238	251	219	258
Ch 321	231	235	249	243	218	207	205	180	155	158
Ch 331	130	116	98	97	79	90	78	83	65	59
Ch 341	79	71	96	80	64	73	69	70	65	64
Ch 351	73	62	58	57	60	62	58	59	45	38
Ch 361	56	49	63	54	57	58	43	51	49	63
Ch 371	60	48	45	37	46	47	43	39	38	30
Ch 381	29	31	29	37	21	20	24	20	32	15
Ch 391	20	23	26	30	29	34	20	20	18	14

APPENDIX C

Table 1. **Spectral analysis of "inelastic gamma ray spectra" from sandpit, counted for live time of 1800s, four repetitions.**

Element (Energy MeV)	Sample	Total Counts	Background Counts	Net Counts	Net normalized to 1016439 neutrons	Neutron Counts (1800s)	ICR (counts/sec)
Na (0.44)	Sand (0.0%C)	2724794	1798096	926698 ±2180	877479 ± 2014	1073452	12240
		2839611	1857762	981848 ± 2167	955992 ± 2110	1043930	12526
		2661038	1714948	946090 ± 2092	982690 ± 2173	978582	11386
		2782066	1825978	956087 ± 2146	1002072 ± 2249	969794	12731
	Sand (2.5%C)	2464987	1637368	827619 ± 2025	857320 ± 2098	981225	11395
		2512769	1669910	842858 ± 2045	874198 ± 2121	980000	11900
		2486606	1628762	857843 ± 2029	909549 ± 2151	958657	11625
		2474032	1620809	853222 ± 2023	902925 ± 2141	960487	11625
	Sand (5%C)	2336258	1525850	810407 ± 1965	830201 ± 2013	992205	11612
		2506187	1677920	828267 ± 2045	851011 ± 2101	989274	11708
		2514204	1688768	825436 ± 2050	863899 ± 2146	971184	11536
		2470122	1672440	797682 ± 2035	840088 ± 2143	965131	11987
	Sand (10%C)	2429437	1609752	819685 ± 2009	817358 ± 2003	1019333	11821
		2537780	1699561	838219 ± 2058	842500 ± 2069	1011274	12158
		2459291	1635122	824168 ± 2023	835792 ± 2052	1002303	12642
		2593578	1766169	827408 ± 2088	869641 ± 2195	967077	12156

Element (Energy MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron Counts (1800s)	ICR (counts/sec)
Si (1.78)	Sand (0.0%C)	530717	476740	53977 ±1003	51110 ± 950	1073452	12240
		580334	524320	56014 ±1051	54539 ± 1023	1043930	12526
		535027	481586	53441 ±1008	55508 ± 1047	978582	11386
		578358	521401	56957 ±1048	59697 ± 1098	969794	12731
	Sand (2.5%C)	512016	462492	49524 ± 987	51301 ± 1022	981225	11395
		514705	463925	50779 ± 989	52667 ± 1026	980000	11900
		488957	439113	49843 ± 963	52847 ± 1021	958657	11625
		485291	435956	49335 ± 960	52209 ± 1016	960487	11625
	Sand (5%C)	454352	408862	45489 ± 929	46600 ± 952	992205	11612
		516901	469742	47158 ± 993	48453 ± 1020	989274	11708
		522075	473466	48609 ± 998	50874 ± 1045	971184	11536
		516932	467630	49301 ± 992	51922 ± 1045	965131	11987
	Sand (10%C)	546378	489384	56994 ±1017	56832 ± 1014	1019333	11821
		524270	470878	53391 ± 997	53664 ± 1002	1011274	12158
		482327	434305	48022 ± 957	48699 ± 970	1002303	12642
		539909	486970	52938 ±1013	55640 ±1065	967077	12156

Element (Energy MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron Counts (1800s)	ICR (counts/sec)
C (4.43)	Sand (0.0%C)	202682	196986	5696 ±632	5393 ± 598	1073452	12240
		230357	225578	4779 ±675	4653 ± 657	1043930	12526
		212753	207580	5173 ±648	5373 ± 673	978582	11386
		225789	220218	5571 ±668	5839 ± 700	969794	12731
	Sand (2.5%C)	195589	188450	7139 ±620	7395 ± 642	981225	11395
		202641	195576	7065 ±631	7328 ± 654	980000	11900
		187625	180608	7017 ±607	7440 ± 644	958657	11625
		183580	176812	6768 ±600	7162 ± 635	960487	11625
	Sand (5%C)	180662	170472	10190 ±593	10439 ± 607	992205	11612
		202854	192412	10442 ±629	10729 ± 646	989274	11708
		204615	193942	10673 ±631	11170 ± 660	971184	11536
		203198	193592	9606 ±630	10117 ± 663	965131	11987
	Sand (10%C)	227033	211144	15889 ±662	15844 ± 660	1019333	11821
		215124	199692	15432 ±644	15511 ± 647	1011274	12158
		200152	185076	15076 ±621	15289 ± 630	1002303	12642
		229752	214970	14782 ±667	15537 ± 701	967077	12156

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron Counts (1800s)	ICR
O (6.13)	Sand (0.0%C)	186538	167145	19393 ± 595	18363 ± 563	1073452	12240
		211305	189639	21665 ± 633	21094 ± 616	1043930	12526
		193664	173567	20097 ± 606	20874 ± 629	978582	11386
		205125	184734	20390 ± 624	21371 ± 654	969794	12731
	Sand (2.5%C)	175431	156368	19063 ± 576	19747 ± 597	981225	11395
		178301	158292	20008 ± 580	20751 ± 602	980000	11900
		165846	145763	20084 ± 558	21295 ± 592	958657	11625
		163729	143221	20508 ± 554	21703 ± 586	960487	11625
	Sand (5%C)	157796	139072	18724 ± 545	19181 ± 558	992205	11612
		178716	157887	20829 ± 580	21401 ± 596	989274	11708
		177586	155848	21737 ± 577	22750 ± 604	971184	11536
		176671	158374	18296 ± 579	19269 ± 610	965131	11987
	Sand (10%C)	192161	171012	21148 ± 603	21088 ± 601	1019333	11821
		181759	161397	20361 ± 586	20465 ± 589	1011274	12158
		169495	148843	20651 ± 564	20942 ± 572	1002303	12642
		190880	170354	20526 ± 601	21574 ± 632	967077	12156

Table 2. **Spectral analysis of "Prompt gamma ray spectra" from sandpit, counted for live time of 1800s, four repetitions.**

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron counts (1800s)	ICR
B/Na (0.47)	Sand (0.0%C)	1228339	774116	454223 ± 1415	475870 ± 1482	970201	12410
	Sand (2.5%C)	1161108	713794	447315 ± 1369	457094 ± 1399	994693	11756
		1221011	780119	440891 ± 1415	459635 ± 1475	974989	11906
		1286320	837262	449058 ± 1457	474533 ± 1540	961873	11587
		1311132	859940	451193 ± 1473	478781 ± 1563	957871	11593
	Sand (5%C)	1227956	771306	456649 ± 1414	476493 ± 1475	974109	12072
		1284461	831109	453352 ± 1454	472363 ± 1515	975531	11852
		1259883	807678	452206 ± 1438	475507 ± 1512	966631	12130
	Sand(10%C)	1419005	930488	488517 ± 1533	502653 ± 1577	987854	12345
		1327021	830485	496536 ± 1469	523682 ± 1549	963750	12658
Si (1.78)	Sand (0.0%C)	171589	161372	10217 ± 577	10704 ± 604	970201	12410
	Sand (2.5%C)	168529	152128	16401 ± 566	16760 ± 578	994693	11756
		185844	169309	16534 ± 596	17237 ± 621	974989	11906
		194159	180600	13559 ± 612	14328 ± 647	961873	11587
		202587	188265	14322 ± 625	15198 ± 663	957871	11593
	Sand (5%C)	177784	163523	14261 ± 584	14881 ± 609	974109	12072
		190474	176977	13497 ± 606	14063 ± 631	975531	11852
		190484	174003	16481 ± 604	17330 ± 635	966631	12130

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron counts (1800s)	ICR
Si (1.78)	Sand (10%C)	218422	201820	16602 ± 648	17082 ± 667	987854	12345
		195334	179451	15883 ± 612	16751 ± 645	963750	12658
H (2.22)	Sand	95014	92819	2194 ± 433	2299 ± 454	970201	12410
	Sand (2.5%C)	118634	112345	6289 ± 481	6426 ± 492	994693	11756
		114939	109328	5611 ± 474	5850 ± 494	974989	11906
		132624	125320	7304 ± 508	7718 ± 537	961873	11587
		134577	129848	4730 ± 514	5019 ± 545	957871	11593
	Sand (5%C)	120213	114986	5228 ± 485	5455 ± 506	974109	12072
		125599	119675	5925 ± 495	6173 ± 516	975531	11852
		117887	113100	4787 ± 481	5034 ± 506	966631	12130
	Sand (10%C)	144438	137802	6636 ± 531	6828 ± 546	987854	12345
		134701	125874	8827 ± 510	9309 ± 538	963750	12658
Si (3.54)	Sand	73509	66458	7050 ± 374	7386 ± 392	970201	12410
	Sand (2.5%C)	89011	76439	12572 ± 407	12847 ± 416	994693	11756
		85869	73654	12215 ± 399	12734 ± 416	974989	11906
		94023	82117	11906 ± 420	12581 ± 444	961873	11587
		97469	86825	10644 ± 429	11295 ± 455	957871	11593

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron counts (1800s)	ICR
Si (3.54)	Sand (5%C)	89915	78450	11465 ± 410	11963 ± 428	974109	12072
		91731	79636	12095 ± 414	12602 ± 431	975531	11852
		88369	76318	12051 ± 406	12672 ± 427	966631	12130
	Sand (10%C)	104964	93271	11693 ± 445	12031 ± 458	987854	12345
		99890	86909	12980 ± 432	13690 ± 456	963750	12658

APPENDIX D

Table 1. **Spectral analysis of "inelastic gamma ray spectra" from a Pine Stand, Sand Patch, Oak Forest, and Sandy Soil (bldg830), counted for live time of 1800s.**

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron Counts (1800s)	ICR
Na (0.44)	Pine Stand *Leaves*	2716688	2007404	709284 ± 2173	735142 ± 2252	980687	15770
	Pine Stand *No-leaves*	2639350	1934240	705110 ± 2139	743481 ± 2255	963981	14630
	Sand Patch	1685880	1158209	527670 ± 1686	542773 ± 1734	988156	10486
	Oak Forest *No-leaves*	2514067	1866398	647668 ± 2093	660658 ± 2135	996454	15045
	Sandy Soil *(Bldg.830)*	(1)2295575 (2)2250144	(1)1599468 (2)1552322	(1)696107 ± 1974 (2)697821 ± 1950	- -	- -	(1)11100 (2)10935
	Sandy Soil 70lbs bags 10%C *(Bldg.830)*	2682970	1931589	751380 ± 2148	-	-	12155
Si (1.78)	Pine Stand *Leaves*	601597	541016	60581 ± 1069	62790 ± 1108	980687	15770
	Pine Stand *No-leaves*	579634	525096	54538 ± 1051	57506 ± 1108	963981	14630
	Sand Patch	344713	313256	31457 ± 811	32357 ± 834	988156	10486
	Oak Forest *No-leaves*	565945	516118	49826 ± 1040	50825 ± 1061	996454	15045
	Sandy Soil *(Bldg.830)*	(1)453264 (2)438024	(1)438722 (2)422702	(1)14541 ± 944 (2)15322 ± 928	- -	- -	(1)11100 (2)10935

	Sandy Soil 70lbs bags 10%C *(Bldg.830)*	541407	518093	23313 ± 1029	-	-	12155

C (4.43)	Pine Stand *Leaves*	232224	220152	12072 ± 673	12512 ± 698	980687	15770
	Pine Stand *No-leaves*	223147	212638	10508 ± 660	11080 ± 696	963981	14630
	Sand Patch	123646	118768	4878 ± 492	5018 ± 506	988156	10486
	Oak Forest *No-leaves*	211148	200768	10380 ± 642	10588 ± 655	996454	15045
	Sandy Soil *(Bldg.830)*	(1)192371 (2)181313	(1)184200 (2)173342	(1)8171 ± 614 (2)7971 ± 596	- -	- -	(1)11100 (2)10935
	Sandy Soil 70lbs bags 10%C *(Bldg.830)*	230697	218296	12400 ± 670	-	-	12155
O (6.13)	Pine Stand *Leaves)*	218758	185475	33283 ± 636	34496 ± 659	980687	15770
	Pine Stand *No-leaves*	206367	177580	28787 ± 620	30354 ± 654	963981	14630
	Sand Patch	105520	91602	13918 ± 444	14316 ± 457	988156	10486
	Oak Forest *No-leaves*	192536	164092	28443 ± 597	29013 ± 609	996454	15045
	Sandy Soil *(Bldg.830)*	(1)161415 (2)152639	(1)143821 (2)133817	(1)17594 ± 552 (2)18821 ±535	- -	- -	(1)11100 (2)10935
	Sandy Soil 70lbs bags 10%C *(Bldg.830)*	196588	174722	21866 ± 609	-	-	12155

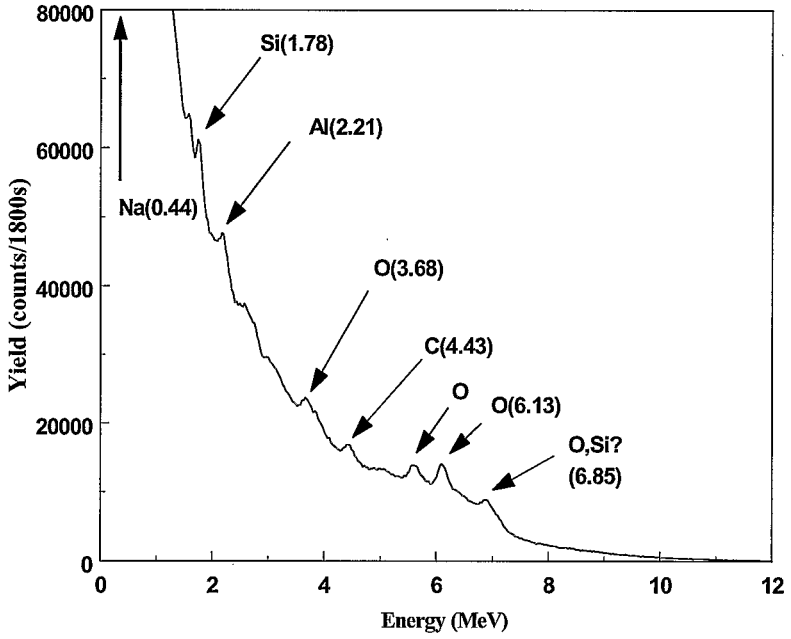
Table 2. Spectral analysis of "prompt gamma ray spectra" from a Pine Stand, Sand Patch, Oak Forest, and Sandy Soil (bldg830), counted for live time of 1800s.

Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron counts (1800s)	ICR
B/Na (0.47)	Pine Stand *leaves*	1546312	1117802	428510 ± 1632	448544 ± 1708	971041	16076
	Site1 *-leaves*	1530520	1101669	428851 ± 1622	452395 ± 1711	963540	15778
	Site2 SANDY	1248382	877349	371034 ± 1458	372967 ± 1466	1011172	11390
	Site3 *-leaves*	1540910	1128495	412414 ± 1634	422597 ± 1674	991946	15970
	Outside Bldg830	1225763	870545	355217 ± 1448	-	-	10513
	Outside Bldg830 70lbs sand, 10%Cbag buried	1369528	914883	454645 ± 1511	-	-	12615
Si (1.78)	Site1 *leaves*	309146	274540	34606 ± 764	36224 ± 800	971041	16076
	Site1 *-leaves*	296146	264673	31472 ± 749	33200 ± 790	963540	15778
	Site2 SANDY	237784	216924	20860 ± 674	20969 ± 678	1011172	11390
	Site3 *-leaves*	322235	291014	31220 ± 783	31991 ± 802	991946	15970
	Outside Bldg830	213705	206244	7461 ± 648	-	-	10513
	Outside Bldg830 70lbs sand, 10%Cbag buried	226774	216944	9830 ± 666	-	-	12615

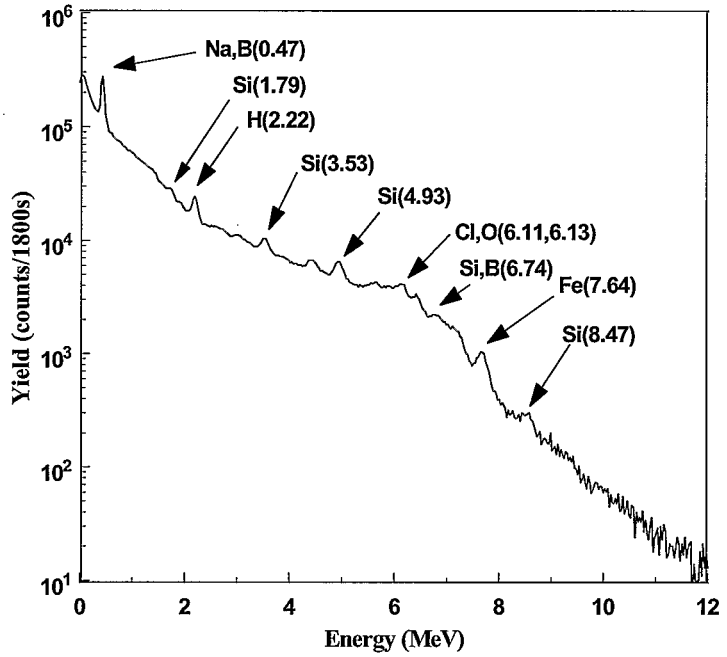
Element (Energy,MeV)	Sample	Total	Background	Net	Net normalized to 1016439 neutrons	Neutron counts (1800s)	ICR
H (2.22)	Site1 *leaves*	299377	197626	101750 ± 705	106507 ± 738	971041	16076
	Site1 *-leaves*	286532	192617	93916 ± 692	99072 ± 730	963540	15778
	Site2 SANDY	192825	161639	31187 ± 595	31349 ± 598	1011172	11390
	Site3 *-leaves*	340910	222068	118842 ± 750	121776 ± 769	991946	15970
	Outside Bldg830	178728	149953	28775 ± 573	-	-	10513
	Outside Bldg830 70lbs sand, 10%Cbag buried	179292	148692	30599 ± 573	-	-	12615
Si (3.54)	Site1 *leaves*	133525	108929	24596 ± 492	25746 ± 515	971041	16076
	Site1 *-leaves*	128946	107290	21655 ± 486	22844 ± 513	963540	15778
	Site2 SANDY	114620	99242	15378 ± 462	15458 ± 464	1011172	11390
	Site3 *-leaves*	140548	117645	22903 ± 508	23469 ± 521	991946	15970
	Outside Bldg830	102700	92598	10102 ± 442	-	-	10513
	Outside Bldg830 70lbs sand, 10%Cbag buried	107066	92935	14130 ± 447	-	-	12615

APPENDIX E

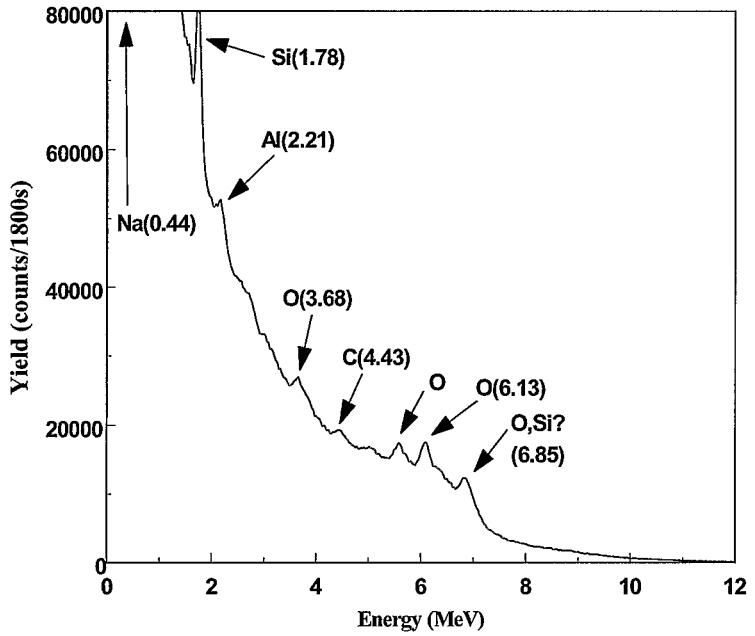
MEASURED SPECTRA IN THE SAND PIT AND IN THE FOREST.



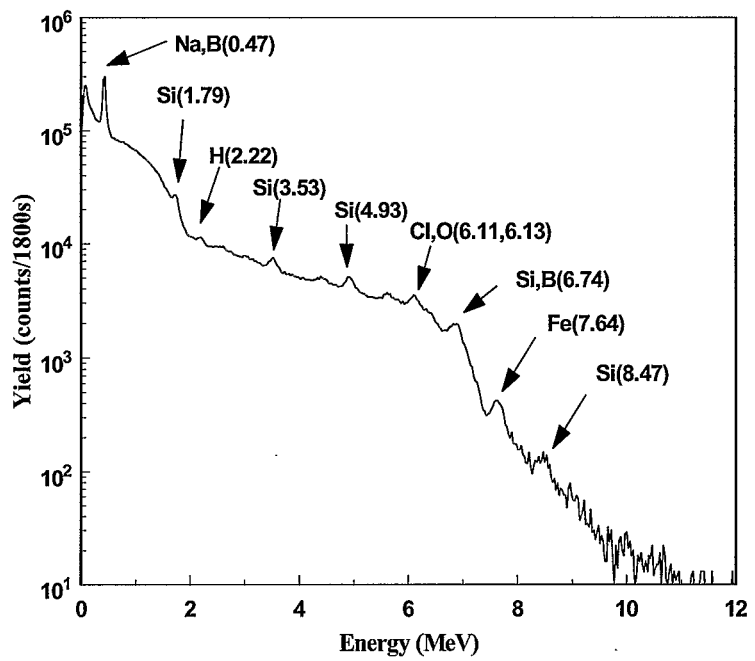
Inelastic gamma ray spectrum from "sandy" soil.



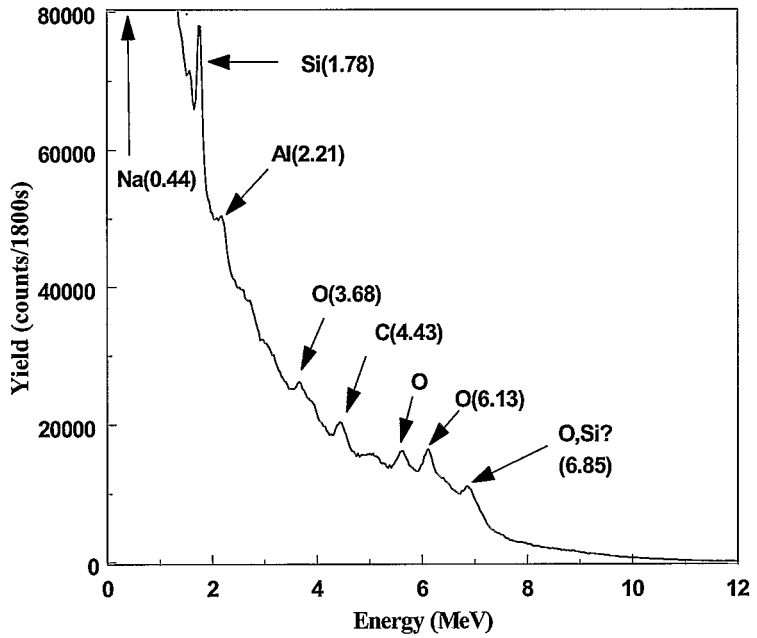
Prompt gamma ray spectrum from "sandy" soil.



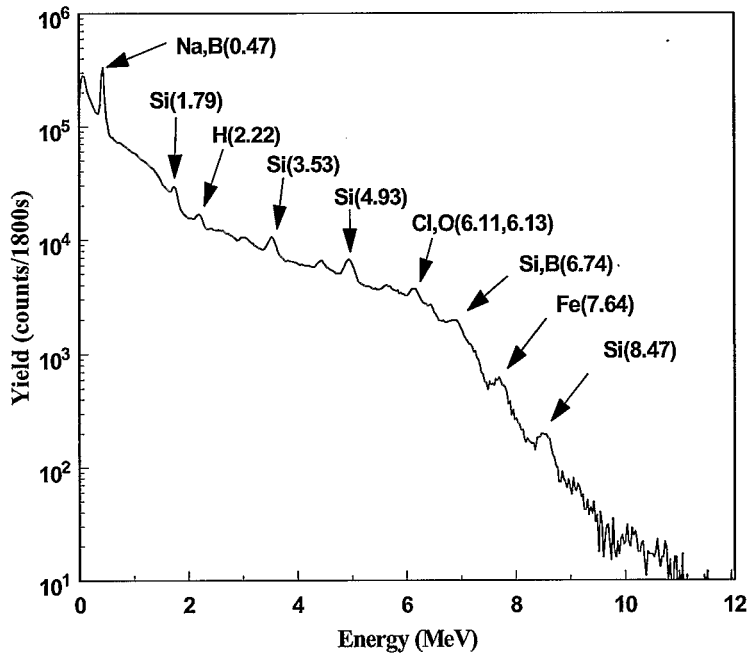
Inelastic gamma ray spectrum from sand (0% C).



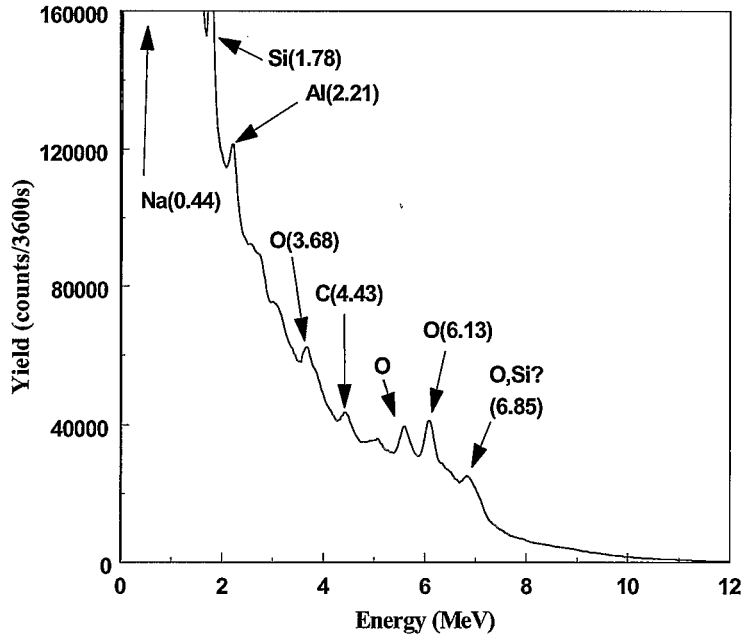
Prompt gamma ray spectrum from sand (0%C).



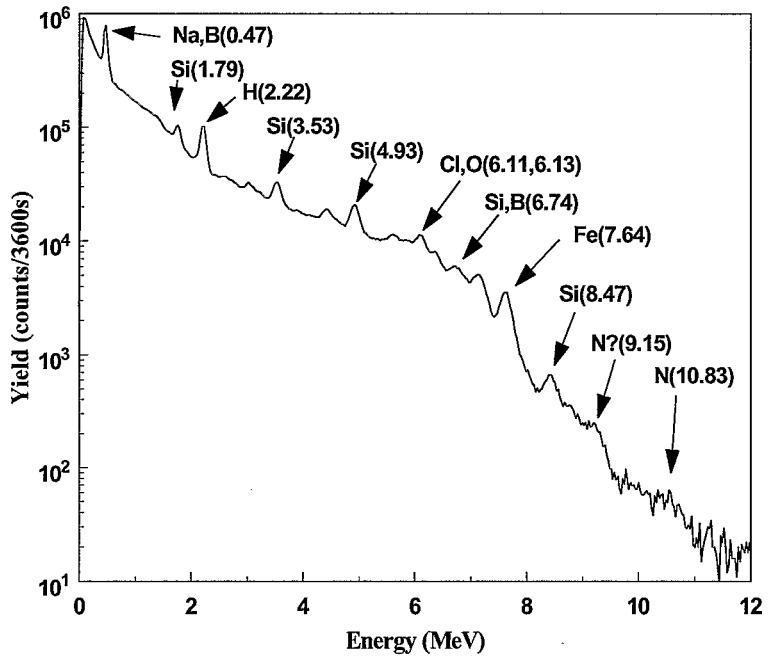
Inelastic gamma ray spectrum from sand (10% C).



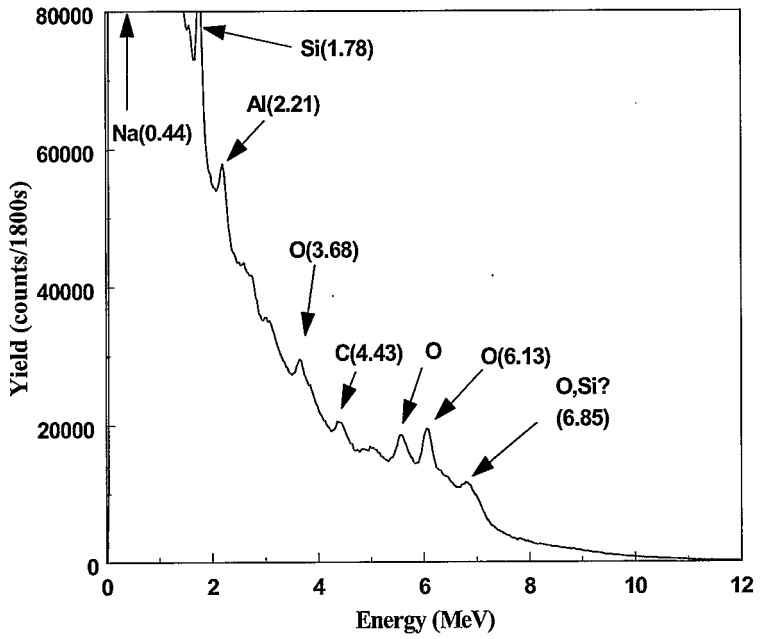
Prompt gamma ray spectrum from sand (10%C).



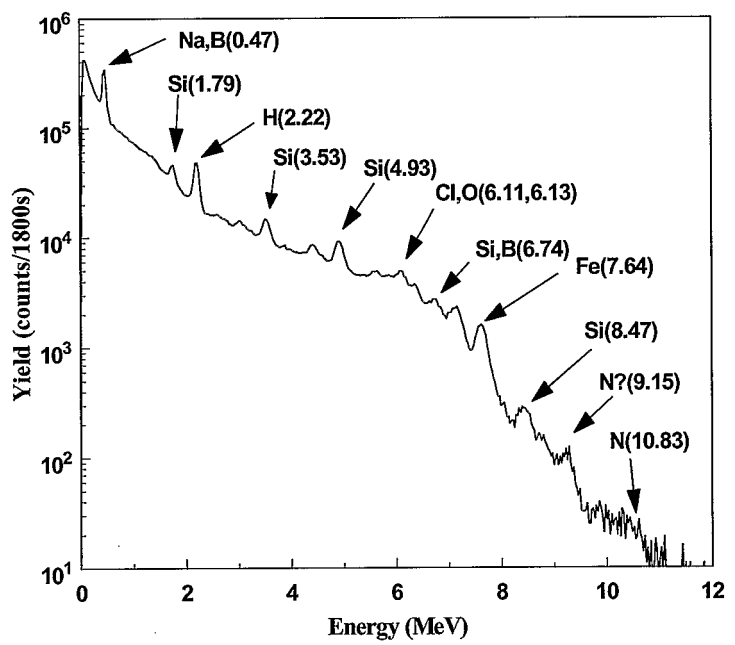
Inelastic gamma ray spectrum from soil at the Pine stand.



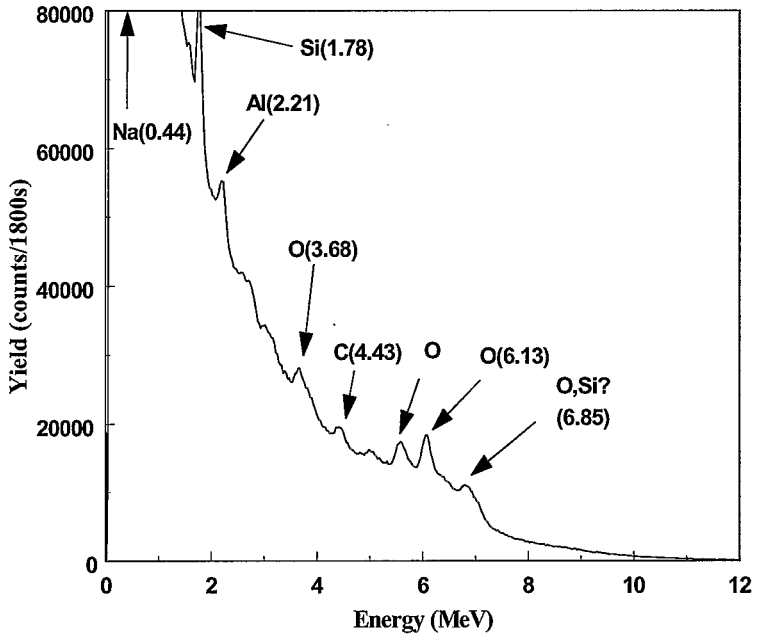
Prompt gamma ray spectrum from soil at the Pine stand.



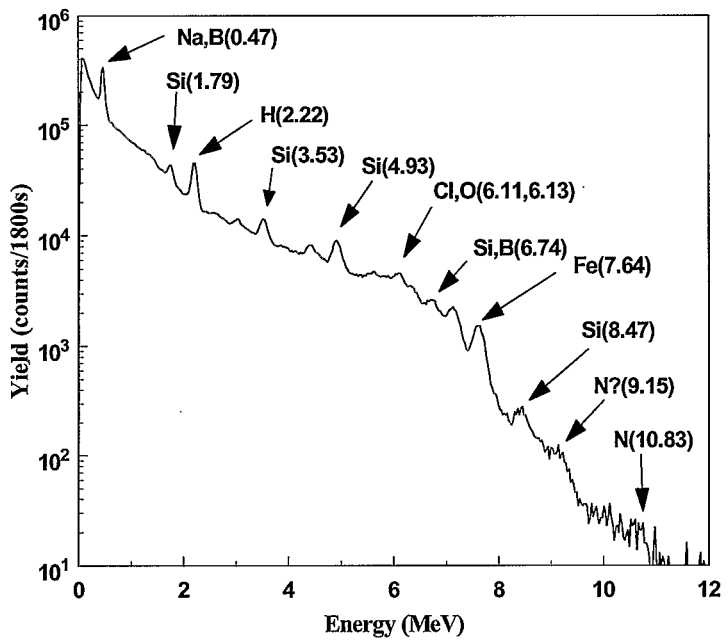
Inelastic gamma ray spectrum from soil (with leaves) at the Pine stand



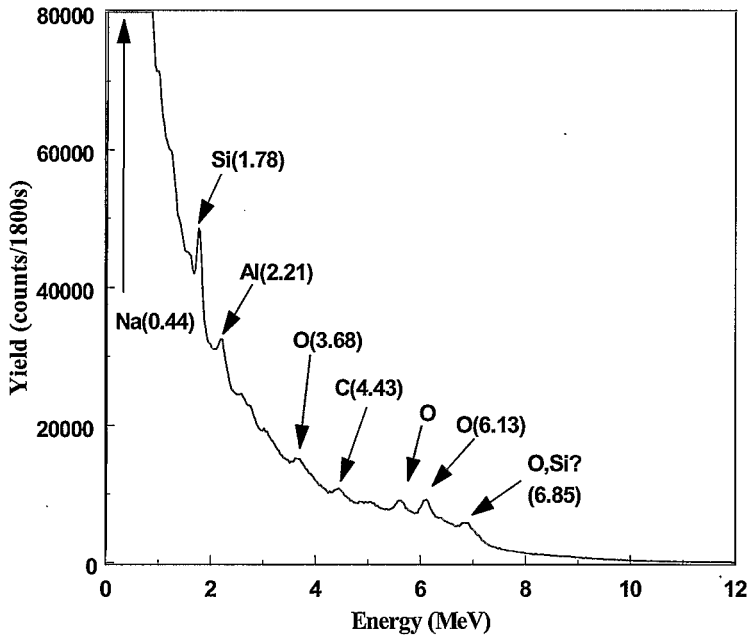
Prompt gamma ray spectrum from soil (with leaves) at the Pine stand.



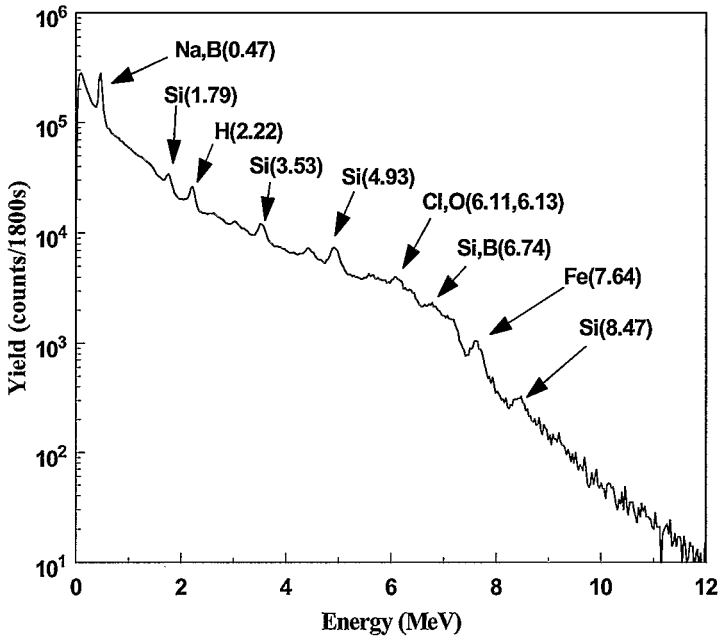
Inelastic gamma ray spectrum from soil (without leaves) in the Pine stand.



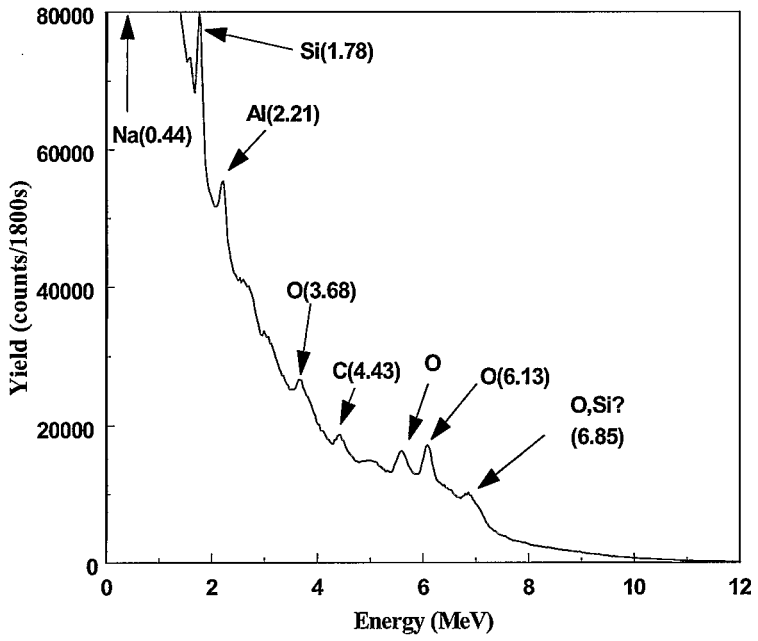
Prompt gamma ray spectrum from soil (without leaves) in the Pine stand.



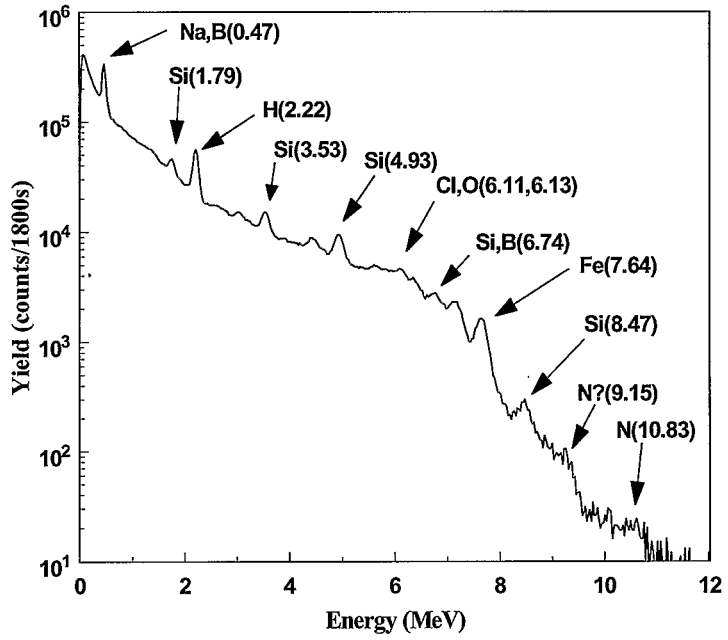
Inelastic gamma ray spectrum from the "sandy" patch (Site 2).



Prompt gamma ray spectrum from the "sandy" patch (Site2).



Inelastic gamma ray spectrum from soil (without leaves) in the Oak forest.



Prompt gamma ray spectrum from soil (without leaves) in the Oak forest.

Appendix F

Brookhaven National Laboratory - soil samples collected 7-2-02

% Carbon*

Site 1 (pine trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
0-5	5.01	5.06	10.56	15.12	6.718
	5.06	5.075	11.07	15.11	6.754
5-10	1.942	1.942	2.662	2.364	1.935
	1.983	2.065	2.759	2.373	1.924
10-20	1.224	1.563	1.286	1.95	1.154
	1.219	1.556	1.28	1.981	1.154
20-30	0.785	0.7849	1.029	0.9409	1.038
	0.7946	0.7938	1.035	0.9171	1.095
30-40	0.4239	0.6799	1.151	0.6625	0.7638
	0.4384	0.7108	1.148	0.6721	0.7699

Site 2 (bare)(2nd debris layer)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
		% Carbon*			
0-5	1.16	1.36	1.323	1.13	1.262
	1.172	1.381	1.392	1.212	1.28
5-10	0.952	0.6859	0.8587	0.8381	0.8366
	0.9343	0.7043	0.8701	0.865	0.8266
10-20	0.4463	0.4171	0.5088	0.3451	0.363
	0.441	0.4125	0.5235	0.3446	0.3731
20-30	0.4867	0.5488	0.3422	0.8234	0.488
	0.473	0.5394	0.3336	0.8021	0.4936
30-40	0.3917	0.4467	0.5033	0.3941	0.28
	0.38	0.4607	0.4831	0.372	0.273

Site 3 (oak trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
		% Carbon*			
0-5	26.82	8.255	17.45	10.57	14.03
	26.99	8.11	17.86	10.84	13.96
5-10	1.664	1.993	2.371	2.393	2.354
	1.667	1.983	2.332	2.499	2.362
10-20	0.79	0.8788	0.8977	0.9675	1.221
	0.7656	0.892	0.9266	0.9959	1.191
20-30	0.5086	1.798	0.7767	0.7286	0.5467
	0.5187	1.793	0.6984	0.7344	0.5325
30-40	0.4619	0.7805	0.3438	0.5923	0.5249
	0.4489	0.8	0.3479	0.5963	0.5215

Sand (Blank)	%C	Soil from Outside	%C
	0.043		5.349
	0.042		5.324

*Carbon analysis by LECO Corporation CN2000 analyzer (combustion furnace at 1350 C)
National Soil Dynamics Laboratory, Auburn, AL

Brookhaven National Laboratory - soil samples collected 7-2-02

% Nitrogen*

Site 1 (pine trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
0-5	0.2036	0.1969	0.3439	0.5305	0.2540
	0.2069	0.1995	0.3529	0.5287	0.2577
5-10	0.0798	0.0804	0.0967	0.0972	0.0857
	0.0806	0.0871	0.0970	0.0927	0.0851
10-20	0.0562	0.0659	0.0538	0.0739	0.0503
	0.0543	0.0648	0.0562	0.0781	0.0539
20-30	0.0400	0.0383	0.0461	0.0412	0.0538
	0.0380	0.0436	0.0428	0.0421	0.0556
30-40	0.0256	0.0296	0.0458	0.0356	0.0328
	0.0276	0.0303	0.0433	0.0360	0.0349

Site 2 (bare)(2nd debris layer)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
		% Nitrogen*			
0-5	0.0681	0.0807	0.0765	0.0684	0.0759
	0.0693	0.0817	0.0777	0.0653	0.0770
5-10	0.0492	0.0400	0.0501	0.0439	0.0448
	0.0506	0.0419	0.0474	0.0465	0.0460
10-20	0.0294	0.0275	0.0300	0.0246	0.0189
	0.0263	0.0282	0.0301	0.0206	0.0196
20-30	0.0261	0.0269	0.0203	0.0316	0.0244
	0.0259	0.0225	0.0142	0.0278	0.0256
30-40	0.0224	0.0254	0.0242	0.0195	0.0164
	0.0214	0.0258	0.0208	0.0187	0.0155

Site 3 (oak trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
		% Nitrogen*			
0-5	0.9014	0.3140	0.5663	0.3925	0.4978
	0.9102	0.3143	0.5809	0.4023	0.4993
5-10	0.0746	0.0786	0.0828	0.0794	0.0881
	0.0723	0.0803	0.0834	0.0823	0.0858
10-20	0.0441	0.0430	0.0409	0.0428	0.0519
	0.0384	0.0399	0.0443	0.0436	0.0491
20-30	0.0279	0.0408	0.0294	0.0355	0.0303
	0.0297	0.0422	0.0284	0.0372	0.0309
30-40	0.0277	0.0271	0.0228	0.0203	0.0270
	0.0277	0.0268	0.0225	0.0232	0.0274

Sand (Blank) %C	Soil from Outside %C
0.0009	0.008
0.0002	0.010

*Nitrogen analysis by LECO Corporation CN2000 analyzer (combustion furnace at 1350 C)
National Soil Dynamics Laboratory, Auburn, AL

Brookhaven National Laboratory - soil samples collected 7-2-02

Bulk Density

Site 1 (pine trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5	Avg
0-5	1.11	1.01	0.85	0.64	1.01	0.92
5-10	0.92	1.14	1.25	1.00	1.21	1.11
10-20	1.42	1.31	1.47	1.23	1.40	1.37
20-30	1.45	1.54	1.53	1.34	1.42	1.46
30-40	1.52	1.49	1.52	1.35	1.34	1.44

Site 2 (bare)(2nd debris layer)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5	Avg
0-5	1.93	1.87	1.85	2.02	2.09	1.95
5-10	1.92	1.81	1.89	2.00	1.86	1.90
10-20	2.11	2.08	2.09	2.07	2.11	2.09
20-30	2.08	2.01	2.12	1.91	2.07	2.04
30-40	1.92	1.90	1.95	2.00	2.07	1.97

Site 3 (oak trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5	Avg
0-5	0.40	0.86	0.52	0.62	0.62	0.61
5-10	1.17	1.09	1.09	1.13	1.09	1.11
10-20	1.30	1.50	1.36	1.45	1.36	1.39
20-30	1.49	1.40	1.47	1.52	1.36	1.45
30-40	1.48	1.51	1.58	1.48	1.42	1.50

Brookhaven National Laboratory - soil samples collected 7-2-02

Moisture Content (g)

H2O (g)

Site 1 (pine trees)

Depth (cm)	Core 1	Core 2	Core 3	Core 4	Core 5
0-5	8.32	7.44	13.03	10.19	7.81
5-10	4.39	5.41	7.59	5.06	5.54
10-20	11.43	11.96	11.53	11.03	11.11
20-30	11.81	10.99	11.91	10.08	11.03
30-40	11.08	11.29	12.60	10.14	11.19

Site 2 (bare)(2nd debris layer)

Depth (cm)					
0-5	6.2	6.19	4.91	5.61	5.24
5-10	5.97	5.22	5.02	5.23	4.22
10-20	9.34	9.59	10.64	10.39	10.43
20-30	14.79	13.95	12.76	15.25	15.38
30-40	15.96	17.69	18.19	19.01	16.6

Site 3 (oak trees)

Depth (cm)					
0-5	15.13	11.79	14.46	10.61	12.72
5-10	9.79	8.8	9.53	8.5	9.41

10-20	19.75	21.31	20.87	19.21	21.18
20-30	23.56	24.17	22.67	20.15	20.03
30-40	26.15	24.67	21.71	20.17	22.56

Brookhaven National Lab Soil Samples: Collected July 2, 2002

Depth of/to organic horizon (cm)

Site 1	Core1	0-1.5
	Core2	0-2.0
	Core3	0-2.5
	Core4	0-3.0
	Core5	0-2.0
Site 2	Core1	25-30
	Core2	24-30
	Core3	27-30
	Core4	24-29
	Core5	24-28
Site 3	Core1	0-6.0
	Core2	0-6.0
	Core3	0-7.0
	Core4	0-6.0
	Core5	0-8.0

Brookhaven National Lab Soil Samples: Collected July 2, 2002

See also next sheet for C table

Site/Core	Depth (cm)	Length (cm)	Wet wt (g)	Dry wt (g)	Grams H2O	BulkDen	%C 1	%C 2	Avg %C
S1 C1	0-5	5	71.16	62.84	8.32	1.11	5.01	5.06	5.035
	5-10	5	56.69	52.30	4.39	0.92	1.942	1.983	1.9625
	10-20	10	172.63	161.20	11.43	1.42	1.224	1.219	1.2215
	20-30	10	176.76	164.95	11.81	1.45	0.785	0.7946	0.7898
	30-40	10	183.4	172.32	11.08	1.52	0.4239	0.4384	0.43115
S1 C2	0-5	5	64.94	57.50	7.44	1.01	5.06	5.075	5.0675
	5-10	5	70.22	64.81	5.41	1.14	1.942	2.065	2.0035
	10-20	10	160.83	148.87	11.96	1.31	1.563	1.556	1.5595
	20-30	10	185.27	174.28	10.99	1.54	0.7849	0.7938	0.78935
	30-40	10	180.74	169.45	11.29	1.49	0.6799	0.7108	0.69535
S1 C3	0-5	5	61.16	48.13	13.03	0.85	10.56	11.07	10.815
	5-10	5	78.59	71.00	7.59	1.25	2.662	2.759	2.7105
	10-20	10	178.03	166.50	11.53	1.47	1.286	1.28	1.283
	20-30	10	185.69	173.78	11.91	1.53	1.029	1.035	1.032
	30-40	10	184.49	171.89	12.60	1.52	1.151	1.148	1.1495
S1 C4	0-5	5	46.43	36.24	10.19	0.64	15.12	15.11	15.11
	5-10	5	61.84	56.78	5.06	1.00	2.364	2.373	2.3685
	10-20	10	150.11	139.08	11.03	1.23	1.95	1.981	1.9655
	20-30	10	162.14	152.06	10.08	1.34	0.9409	0.9171	0.929
	30-40	10	163.15	153.01	10.14	1.35	0.6625	0.6721	0.6673
S1 C5	0-5	5	64.85	57.04	7.81	1.01	6.718	6.754	6.736
	5-10	5	74.25	68.71	5.54	1.21	1.935	1.924	1.9295
	10-20	10	170.06	158.95	11.11	1.40	1.154	1.154	1.154
	20-30	10	172.51	161.48	11.03	1.42	1.038	1.095	1.0665
	30-40	10	163.66	152.47	11.19	1.34	0.7638	0.7699	0.76685
S2 C1	0-5	5	115.51	109.31	6.20	1.93	1.16	1.172	1.166
	5-10	5	114.76	108.79	5.97	1.92	0.952	0.9343	0.94315
	10-20	10	248.79	239.45	9.34	2.11	0.4463	0.441	0.44365
	20-30	10	250.13	235.34	14.79	2.08	0.4867	0.473	0.47985
	30-40	10	234.16	218.20	15.96	1.92	0.3917	0.38	0.38585
S2 C2	0-5	5	112.25	106.06	6.19	1.87	1.36	1.381	1.3705
	5-10	5	108.01	102.79	5.22	1.81	0.6859	0.7043	0.6951
	10-20	10	245.82	236.23	9.59	2.08	0.4171	0.4125	0.4148
	20-30	10	241.67	227.72	13.95	2.01	0.5488	0.5394	0.5441
	30-40	10	232.63	214.94	17.69	1.90	0.4467	0.4607	0.4537
S2 C3	0-5	5	110.06	105.15	4.91	1.85	1.323	1.392	1.3575
	5-10	5	112.36	107.34	5.02	1.89	0.8587	0.8701	0.8644
	10-20	10	247.39	236.75	10.64	2.09	0.5088	0.5235	0.51615
	20-30	10	253.17	240.41	12.76	2.12	0.3422	0.3336	0.3379
	30-40	10	239.75	221.56	18.19	1.95	0.5033	0.4831	0.4932
S2 C4	0-5	5	120.16	114.55	5.61	2.02	1.13	1.212	1.171
	5-10	5	118.58	113.35	5.23	2.00	0.8381	0.865	0.85155

	10-20	10	245.2	234.81	10.39	2.07	0.3451	0.3446	0.34485
	20-30	10	231.56	216.31	15.25	1.91	0.8234	0.8021	0.81275
	30-40	10	246	226.99	19.01	2.00	0.3941	0.372	0.38305
S2 C5	0-5	5	123.56	118.32	5.24	2.09	1.262	1.28	1.271
	5-10	5	109.71	105.49	4.22	1.86	0.8366	0.8266	0.8316
	10-20	10	249.67	239.24	10.43	2.11	0.363	0.3731	0.36805
	20-30	10	250.02	234.64	15.38	2.07	0.488	0.4936	0.4908
	30-40	10	251.4	234.80	16.60	2.07	0.28	0.273	0.2765
S3 C1	0-5	5	37.65	22.52	15.13	0.40	26.82	26.99	26.905
	5-10	5	75.93	66.14	9.79	1.17	1.664	1.667	1.6655
	10-20	10	167.23	147.48	19.75	1.30	0.79	0.7656	0.7778
	20-30	10	192.26	168.70	23.56	1.49	0.5086	0.5187	0.51365
	30-40	10	194.48	168.33	26.15	1.48	0.4619	0.4489	0.4554
S3 C2	0-5	5	60.64	48.85	11.79	0.86	8.255	8.11	8.1825
	5-10	5	70.67	61.87	8.80	1.09	1.993	1.983	1.988
	10-20	10	190.96	169.65	21.31	1.50	0.8788	0.892	0.8854
	20-30	10	183.42	159.25	24.17	1.40	1.798	1.793	1.7955
	30-40	10	196.3	171.63	24.67	1.51	0.7805	0.8	0.79025
S3 C3	0-5	5	44.14	29.68	14.46	0.52	17.45	17.86	17.655
	5-10	5	71.44	61.91	9.53	1.09	2.371	2.332	2.3515
	10-20	10	175.43	154.56	20.87	1.36	0.8977	0.9266	0.91215
	20-30	10	188.88	166.21	22.67	1.47	0.7767	0.6984	0.73755
	30-40	10	201.32	179.61	21.71	1.58	0.3438	0.3479	0.34585
S3 C4	0-5	5	46.01	35.40	10.61	0.62	10.57	10.84	10.705
	5-10	5	72.85	64.35	8.50	1.13	2.393	2.499	2.446
	10-20	10	183.74	164.53	19.21	1.45	0.9675	0.9959	0.9817
	20-30	10	192.09	171.94	20.15	1.52	0.7286	0.7344	0.7315
	30-40	9	171.74	151.57	20.17	1.48	0.5923	0.5963	0.5943
S3 C5	0-5	5	47.91	35.19	12.72	0.62	14.03	13.96	13.995
	5-10	5	70.99	61.58	9.41	1.09	2.354	2.362	2.358
	10-20	10	175.59	154.41	21.18	1.36	1.221	1.191	1.206
	20-30	10	173.87	153.84	20.03	1.36	0.5467	0.5325	0.5396
	30-40	10	183.04	160.48	22.56	1.42	0.5249	0.5215	0.5232

area of circle = 11.341149