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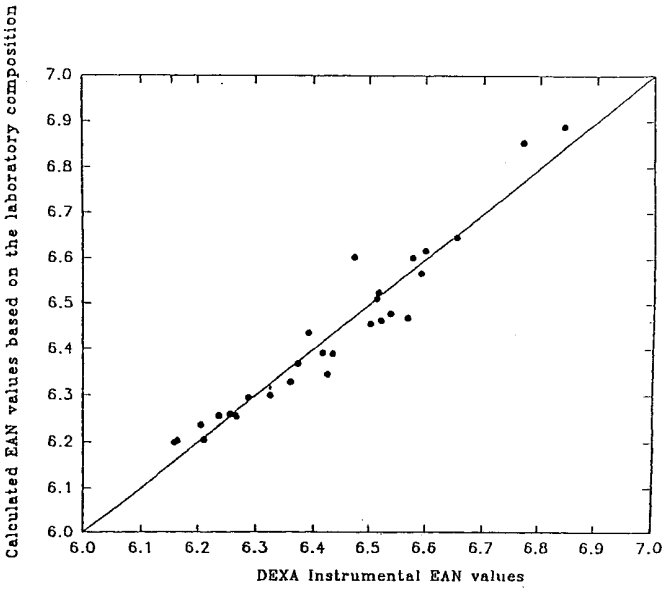
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(54) Title: A METHOD FOR THE NON-INVASIVE ASSESSMENT OF PROPERTIES OF MATERIALS INCLUDING COAL AND WOOL



(57) Abstract: A method for non-invasive assessment of a property or properties of a chemically complex material such as the composition or ash content of coal, or wool, comprises scanning the material with a dual energy x-ray absorption scanner and measuring the intensity of high and low x-ray beams after passing through the material, calculating an effective atomic number for the material, and assessing the property or properties of the material by reference to the effective atomic number calculated for the material. The calculated effective atomic number is compared to stored data correlating effective atomic number to the property or properties of the material.

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A METHOD FOR THE NON-INVASIVE ASSESSMENT OF PROPERTIES OF MATERIALS INCLUDING COAL AND WOOL

FIELD OF INVENTION

The invention comprises a method for the non-invasive assessment of the properties of a chemically complex material such as coal or wool through determination of the effective atomic number.

BACKGROUND

Coal is a complex material comprising carbon, ash, sulphur, moisture and other substances in varying amounts. A sample of coal contains all of the above, and the proportions will depend on the mine from which the coal is taken. The proportions of the substances that make up coal will, to a lesser extent, vary between different coal samples taken within the same mine.

In industry a coal buyer is interested in the ash and moisture content of the coal as a well as the ash composition and the calorific value of the coal. For example coal with a high iron content may clog furnaces and sulphur in coal forms sulphur dioxide, a poisonous gas when burnt. Current methods for measuring the properties of coal include systems, such as ash gauges, that use x-rays and/or gamma-rays. These systems are non-invasive and have been used to determine ash content and the amounts of sulphur and oxygen in coal. These systems only measure the properties of a small amount of the coal produced by a mine and may be time consuming processes. The ability to measure all or a large proportion of the coal on a conveyor belt is important to the coal industry. This information provides an assurance of coal quality to both the coal producer and prospective coal buyers.

Methods also exist for measuring changes in the composition of coal. These methods include x-ray fluorescence devices. X-ray fluorescence is used to measure the concentration of elements within a substance from the intensities of fluorescent radiation emitted when the substance is excited by x-ray radiation. This method is a small sample surface method not useful in on-belt situations. Other laboratory analysis methods also exist for measuring the concentration of chemicals in coal.

Raw wool contains pure wool, water, grease, dirt, suint and vegetable matter in varying amounts. Like coal a sample of wool, from a bale, will contain all of the above substances in proportions that vary from flock to flock and fleece position. A wool buyer is interested in the wool yield per bale where the wool yield refers to the amount of pure wool in the bale. Present methods for determining wool yield include drilling out samples from wool bales with a long hollow drill. Another method involves the use of a dual gamma-ray system.

SUMMARY OF INVENTION

It is the object of the present invention to provide an improved or at least alternative method for the non-invasive measurement of properties of coal and wool.

In broad terms in one aspect the invention comprises a method for non-invasive assessment of a property or properties of a chemically complex material, comprising scanning the material with a dual energy x-ray absorption scanner and measuring the intensity of high and low x-ray beams after passing through the material, calculating an effective atomic number for the material, and assessing the property or properties of the material by reference to the effective atomic number calculated for the material.

Preferably the method includes comparing the calculated effective atomic number to stored data correlating effective atomic number to the property or properties of the material.

Preferably the material passes continuously through the scanner and the effective atomic number is continuously calculated on-line.

In broad terms in another aspect the invention comprises apparatus for non-invasive assessment of a property or properties of a chemically complex material, comprising a dual energy x-ray absorption scanner arranged to scan the material and measure the intensity of high and low x-ray beams after passing through the material, and associated processing means arranged to calculate an effective atomic number for the material and assess the property or properties of the material by reference to the effective atomic number calculated for the material.

Preferably said processing means is arranged to compare the calculated effective atomic number with stored data correlating effective atomic number to the property or properties of the material.

The effective atomic number of a substance, such as coal or wool, is defined as the apparent atomic number if the substance were analysed as a single element. The effective atomic number is usually calculated as a non-linear combination of actual elemental responses. As the composition of a substance changes so too will its effective atomic number.

The coal chemical composition and its effective atomic number depend on the geographical location where the coal was formed. The effective atomic number may be considered as a "fingerprint" of a particular coal mine. Variations of the effective atomic number at differing locations in a particular mine may also be commercially significant. The ash contained in the coal will also have a characteristic effective atomic number related to its unique composition.

Dual energy x-ray absorption scanners produce output intensities of two different x-ray energies in different ways. An x-ray tube working at one voltage, for example 150 keV, will produce x-rays with energies from 150 keV down to 0 keV. To select two x-ray energies from this distribution two detectors may be used where each detector is capable of measuring one of the x-ray energies required. These detectors may be string-like detectors housed above the conveyor belt in a line across the conveyor. The two detectors may be placed one on top of the other, or alternatively side by side above the conveyor. A second method for producing a dual energy output is to rapidly switch the x-ray source between two energy levels. In an x-ray absorption scanner of this form a single detector may be used to detect x-ray intensities at both x-ray energies.

BRIEF DESCRIPTION OF DRAWINGS

The method of the invention will be further described with reference to the accompanying drawings, wherein:

Figure 1 shows coal on a conveyor belt passing through a dual energy x-ray absorption scanner;

Figure 2 shows a cross-sectional view of the scanner scanning coal;

Figure 3 is a plot showing the calculated values of the effective atomic number of coal samples against the effective atomic number calculated using the dual energy x-ray absorption scanner;

Figure 4 is a plot showing variations in the effective atomic number for coal samples with different water content as the ash content varies;

Figure 5 is a plot showing the variations in the ratio of the ash percentage by weight calculated from the output of the dual energy x-ray absorption scanner to the laboratory calculated ash percentage by weight as the percentage weight of aluminium and silicon vary;

Figure 6 is a plot showing the percentage ash by weight calculated from the output of the dual energy x-ray absorption scanner graphed against the percentage ash by weight calculated using laboratory analysis for various sub-bituminous coal mines;

Figure 7 is a plot showing the percentage by weight of ash in the coal samples calculated from the output of the dual energy x-ray absorption scanner graphed against the percentage by weight of ash in the coal samples calculated from the laboratory analysis;

Figure 8 is a plot showing the actual wool yield calculated in a laboratory against the wool yield calculated using the dual energy x-ray absorption scanner;

Figure 9 is a plot showing actual wool base calculated in a laboratory against the wool base calculated using the dual energy x-ray absorption scanner;

Figure 10 is a plot showing actual wool mass calculated in a laboratory against the wool mass calculated using the dual energy x-ray absorption scanner;

Figure 11 is a plot showing the actual wool base calculated in a laboratory against the wool base calculated using the dual energy x-ray absorption scanner for a number of fleeces;

Figure 12 is a graph showing the ability of the dual energy x-ray absorption scanner to produce a meaningful result; and

Figure 13 is a picture of a fleece on a conveyor showing the use of the detector software to detect objects in the wool.

DETAILED DESCRIPTION

Referring to Figure 1 the preferred form apparatus shown comprises a conveyor 15 of any suitable form which carries coal 10 or wool. The scanner 1 is a dual energy x-ray absorption scanner which scans the coal or wool. The output of the scanner is fed via a cable to a computer 25 where the effective atomic number of the coal or wool is determined. The computer compares the calculated effective atomic number to values in a look-up table or database. The computer determines properties of the material based on the effective atomic number and the comparison. The computer may also perform a range of recording and/or storing functions.

Figure 2 shows a cross-sectional view of the scanner scanning coal, through line A-A of Figure 1. The x-ray source is preferably located below a conveyor belt carrying the coal or wool and the x-rays are collimated to form a fan or line across the flow on the conveyor belt. The x-rays penetrate the coal or wool and pass to detectors located above the conveyor belt. A beam of x-rays is produced by the source module 6 positioned below the conveyor belt 15 in scanner housing 5. The source is preferably collimated to a narrow fan shape that passes through the subject material and is intercepted by line detector 7. The scanner comprises suitable radiation shielding.

Line detector 7 in the preferred form is a string of small independent detectors positioned across the scanner above conveyor 15 and is supported by detection equipment. The detectors detect x-ray intensities at two different energy levels, hence the term dual energy x-ray absorption scanner. The detectors and detection equipment enable the energies of the x-rays to be detected after transmission through the coal or wool bales. The detection unit is connected to a computer that performs subsequent data processing.

Typically the scanner comprises an x-ray tube source producing x-rays typically in the energy range 10 to 150 keV and ideally about 140 keV. The scanner further comprises two detectors capable of detecting x-ray intensities at two different energy levels. This utilises the principle of the higher rate-of-loss of x-rays of lower energy in elements. This absorption increases rapidly at higher atomic numbers. We have found it is possible to measure composition for coal or wool rapidly on a moving conveyor belt.

The effective atomic number of coal is calculated as a sum of terms of the form C_zW_zZ divided by the sum of the terms of form C_zW_z, where Z is the atomic number of each contributing element in the coal matrix, C_z is the corresponding number of atoms per unit coal mass and W_z is a corresponding weight representing the relative measurement bias for this element. The measurement bias is determined from the physical principles underlying the measurement process. Many gauge systems employing x-rays have an enhanced sensitivity to higher atomic number elements, because the photo-absorption process is proportional to Z^n/A, where A is the nucleon number and "n" is theoretically as high as 5.

The detection system used by the scanner preferably responds to split out two x-ray energies of about 100 keV and 80 keV thus the term dual energy x-ray. This information is passed to the output of the scanner in terms of the intensity of the high and low energy x-ray beams after passing through the coal or wool. The algorithm used for determining the effective atomic number of a substance passed through the scanner is of the form:

$$\text{Effective Atomic Number} = A*((H-L)/L)+B*H+C$$

where H and L represent the high energy beam and low energy beam intensities respectively and A, B and C are coefficients. A, B and C are initially calculated by comparison of the dual energy x-ray absorption scanner output and the laboratory calculated effective atomic number. These coefficients are specific to the scanner used and also to the application for which the scanner is used. In use when A, B and C are known the effective atomic number is calculated using the above equation. The effective atomic number is then compared to a stored effective atomic number previously calculated.

The computer may decide on grading for the coal based on the effective atomic number. It may also display a graph showing how the effective atomic number of the coal is varying. Alternatively the computer may store the effective atomic numbers for further processing and reporting. The computer may also be used to generate reports based on the effective atomic number of the coal or sound an alarm if the effective atomic number of the coal moves outside pre-set limits.

From the comparison between the calculated effective atomic number and the stored effective atomic number, variations in the coal composition can be detected. Monitoring these variations provides an effective method for on-site grading of coal. For example if the effective atomic number of the coal moves beyond a pre-set limit the coal may be graded into a different category for a different purpose than coal when the effective atomic number remains within preset limits. A precisely determined effective atomic number forms the basis for the determination of commercially important parameters such as water, coal ash and ash composition.

A further use for the dual energy x-ray absorption scanner in scanning coal is predicting the percentage ash by weight in the coal. Ash in coal is made up of many elements including silicon, aluminium and iron. The proportions of these and other elements in the ash vary, as does the overall proportion of coal that is ash. Because of this a single effective atomic number for a sample of coal may not be sufficient to determine the percentage of coal that is ash. Aluminium and silicon represent the lower atomic number components of ash and are often a major contributor to total ash composition. In the laboratory the percentage by weight of coal that is silicon and aluminium is obtained by burning the coal to produce ash oxides, calculating the percentage of the ash oxides that is silicon oxide (SiO_2) and aluminium oxide (Al_2O_3) and then multiplying this percentage by the percentage of coal that is ash.

A further measurement of the aluminium and silicon content in coal may be provided by a supplementary method such as neutron activation. This method uses a separate radiation source such as californium-252 (Cf-252) to turn silicon into aluminium-28 by a neutron in alpha particle out reaction and to turn aluminium-27 into aluminium-28 by neutron capture. Aluminium-28 emits characteristic gamma rays which may be detected by a NaI(Tl) scintillation detector. The result from the detector may be used to indicate the amounts of silicon and aluminium in the coal. Using neutron activation together with the effective atomic number from the dual

energy x-ray absorption scanner output the problem of ash sensitivity is overcome and an accurate prediction of the percentage of coal that is ash may be made.

Another element of importance in coal is iron. The iron content in coal forms part of the ash composition and coal with a high iron content is not useful in some applications because it can clog furnaces. Iron has one of the high atomic components in ash. As the output of the dual energy x-ray absorption scanner varies it is impossible to determine whether the variation is caused by a variation in the total ash content of the coal or by a variation in the composition of the ash.

One method for overcoming this problem and an extension to using a dual energy x-ray absorption scanner is to use a triple energy x-ray absorption scanner capable of detecting x-rays at three different energy levels. A triple energy x-ray absorption scanner will produce an output of the intensities of the high, middle and low energy x-ray beams. For example the high energy x-ray may be at 140 keV, the middle energy x-ray at 100 keV and the low energy x-ray at 80 keV. Denoting the intensities of the high, middle and low energy x-rays as H, L' and L" two different equations for the effective atomic number (EAN) may now be set up as:

$$EAN = A'*(H-L')/L'+B*H+C$$
$$EAN = A''*(H-L'')/L''+B*H+C$$

The values of A, denoted in the above equations as A' and A" will differ due to the energy sensitivity of the x-ray absorption process with energy but also due to the chemical composition of the coal. If a larger amount than normal is present of a substance with a high atomic number, such as iron, the value of A will differ more than if a larger amount than normal is present of a substance with an atomic number close to the effective atomic number of coal. Iron has a higher atomic number than many of the other components of coal and hence the ratio of A' to A" may be related to the iron content in the coal.

Wool is scanned in the same way as coal described above. The raw data produced by the dual energy x-ray absorption scanner is then processed to determine the wool yield from the effective atomic number of the wool scanned. The wool yield is calculated from the output of the scanner as

$$\text{Wool Yield} = A*((H-L)/L)+B*H+C \qquad (wt\%)$$

where H and L are the high energy beam and low energy beam intensities respectively and A, B and C are predetermined coefficients. This gives the wool yield as a percentage weight of the bale. A high wool yield comes from a bale containing mostly pure wool with little water, dirt, grease etc.

Wool yield is a measurement of the percentage of pure wool and water in a quantity of raw wool. Traditionally wool yield has been measured as water is considered part of the useful product. Often it is assumed that pure wool in equilibrium with the atmosphere will contain 16% water and this assumption is used in calculating the wool yield.

The wool base of a fleece is closely related to the wool yield of the fleece. Wool base is a measurement of the amount of pure wool in a quantity of raw wool. Thus the wool base measurement excludes the water content in the raw wool. Using the method of the invention both the wool yield and/or wool base of a quantity of raw wool can be measured.

Figure 3 is a plot showing a comparison of the theoretical and dual energy x-ray absorption scanned effective atomic numbers for 28 New Zealand coal mines. This plot shows that the dual energy x-ray absorption scanner produces data from which the effective atomic number may be calculated, which is an accurate representation of the effective atomic number when calculated based on the laboratory composition. The effective atomic number based on the laboratory composition was calculated using Z in place of W_z in the previously given equation.

Figure 4 is a plot showing the variance in effective atomic number as the percentage content of the ash in the coal varies. Coal with three different moisture contents is graphed for the variation in ash. From this plot it can be seen that a variation of 4% in ash content produces a greater variation in atomic number than a 4% variation in water content.

Figure 5 shows how the ratio of the percentage ash by weight calculated from the output of the dual energy x-ray absorption scanner to the laboratory calculated percentage ash by weight changes as the percentage of aluminium and silicon in the

coal varies. In this figure the filled circles represent the result from samples of bituminous coals, the triangles represent the results from sub-bituminous coals and the open circles represent the results from lignite coals. As the percentage of aluminium and silicon in the coal decreases the ratio of the percentage ash by weight calculated from the output of the dual energy x-ray absorption scanner to calculated in the laboratory increases. This is due to the low atomic numbers of silicon and aluminium compared to other components of the ash. As the percentage of silicon and aluminium in the ash decreases the percentage of elements with a higher atomic number increases and the scanner overestimates the percentage ash in the coal. Figure 5 shows that this overestimation is systematic. If the amount of silicon and aluminium in the coal is known the overestimation of the percentage ash in the coal can be corrected. Figure 5 also shows that the ratio of percentage ash calculated through the output of the coal scanner to that calculated in the laboratory changes differently for different types of coal.

Figure 6 shows the percentage by weight of ash in coal calculated from the scanner output graphed against the percentage by weight of ash in coal calculated in the laboratory for samples of coal taken from sub-bituminous coal mines. From Figure 5 it can be seen that the ratio of the percentage by weight of ash in coal calculated from the output of the scanner to that calculated in the laboratory showed few changes as the percentage of aluminium and silicon in the coal changed for the sub-bituminous coal. Figure 6 shows that the percentage by weight of ash in coal calculated from the output of the scanner is a good indication of the actual percentage by weight of ash in coal as calculated from the laboratory data for sub-bituminous coal mines. This result indicates that for sub-bituminous coal mines the output of the dual energy x-ray absorption scanner is a good indication of the percentage by weight ash in coal.

Figure 7 shows the percentage by weight of ash in the coal samples calculated from the output of the dual energy x-ray absorption scanner graphed against the percentage by weight of ash in the coal samples calculated from the laboratory analysis. The scanner calculated result was calculated using the effective atomic number calculated directly from the output of the dual energy x-ray absorption scanner and a supplementary measurement of the percentage of silicon and aluminium in the coal. The equation used to calculate the ash content is:

$$\% \text{ ash} = A^*EAN(\text{fitted}) + B^*(\%(SiO_2 + Al_2O_3)) + C$$

where EAN(fitted) is the effective atomic number calculated from the output of the dual energy x-ray absorption scanner, $(\%(SiO_2 + Al_2O_3))$ is the percentage of silicon and aluminium in the coal calculated from a supplementary measurement, such as neutron activation, and A, B and C are coefficients which are partly dependent of the scanner used. For the scanner used to produce this graph A = 6.671±0.8, B = 0.955±0.12 and C = -40.77±5. This graph shows that using a supplementary measurement of silicon and aluminium in coal together with the output from the dual energy x-ray absorption scanner an accurate prediction of the percentage ash in coal may be made. In this analysis no account was taken of the moisture content of the coal. As may be seen from figure 4 the moisture content of the coal affects the effective atomic number of the coal calculated from the output of the dual energy x-ray absorption scanner. This graph shows that it is possible to measure the ash content of coal for all coal passing through the dual energy x-ray absorption scanner independent of the ash composition and moisture content of the coal and independent of the type of coal.

Figure 8 shows the actual wool yield calculated in a laboratory graphed against the wool yield calculated from the output of the dual energy x-ray absorption scanner. The wool bales used in this graph came from a range of breeds and cross-breeds of sheep. This graph shows that the wool yield calculated from the output of the dual energy x-ray scanner is an accurate measurement of the actual wool yield as calculated from laboratory tests. In this graph only 5% of the wool was scanned using the dual energy x-ray absorption scanner and better results may be achieved by scanning a greater percentage of the wool.

Figure 9 shows the actual wool base calculated in the laboratory graphed against the wool base calculated from the output of the dual energy x-ray absorption scanner. The fleeces used in this example are "standard fleeces" and the actual wool base was calculated using small samples of the fleece drawn from random positions on the fleeces. This graph shows that the output of the dual energy x-ray absorption scanner can be used to accurately determine the wool base of a fleece.

Figure 10 shows the actual mass of fleeces graphed against the mass of the fleeces calculated from the output of the dual energy x-ray absorption scanner. The

attenuation of x-rays by a material being scanned is dependent on both the mass per unit area of the material and the chemical makeup of the material. Therefore the total mass of the material can be calculated using the attenuation of x-rays in the dual energy x-ray absorption scanner. In this case the mass of the material is calculated as:

mass = sum over all pixels of K1*log(K2/(x-ray beam intensity in pixels))

where K1 and K2 are constants determined from experiment of theory. The fleeces used in this example are the same fleeces used in figure 9. This graph shows that the output of the dual energy x-ray absorption scanner can be sued to accurately determine the mass of a fleece.

Figure 11 shows the actual wool base calculated in the laboratory graphed against the wool base calculated from the output of the dual energy x-ray absorption scanner. The fleeces used in this example are "standard fleeces" and the actual wool base was calculated using small samples of the fleece drawn from random positions on the fleeces. This graph shows that the output of the dual energy x-ray absorption scanner can be used to accurately determine the wool base of a fleece.

Figure 12 shows the ability of the output of the dual energy x-ray absorption scanner to produce a result when used to calculate the wool base of a fleece. The wool base of a single fleece was measured 100 times using a dual energy x-ray absorption scanner and the results plotted on the histogram of figure 12. The fleece used to produce the data has a wool base of around 50. From figure 12 it can be seen that when scanned using the dual energy x-ray absorption scanner and method of the invention the measured wool base ranged from approximately 49 to approximately 52. The standard deviation of the wool base calculated from the histogram of figure 12 is less than 1% or 0.55 wool base units. This means that a measurement or the wool base for a fleece is such that 67% of the readings for repeated measurement fall within ± 0.55 wool base units.

Figure 13 shows the image of a fleece scanned by the dual energy x-ray absorption scanner. The output of the dual energy x-ray absorption scanner can be processed to detect defects such as stones 11, metal fragments 12, or concealed fleece areas 13. Software processing of the output of the dual energy x-ray absorption scanner can be

arranged to separate and count stones, pieces of metal, concealed fleece regions and any other important and distinguishable features of the fleece. The software can also be arranged to store this information with the fleece wool base and/or wool yield value.

Coal is made up from a wide range of elements with differing atomic numbers in differing amounts. Ores and fertilisers also contain a range of elements with both high and low atomic numbers. Therefore the system as described above can also be used for on belt scanning of ores and fertilisers or any complex chemical substance to obtain an accurate effective atomic number for the substance.

The method may also be used to measure the dry matter in potatoes and other root vegetables. The percentage by weight of dry matter in potatoes represents the weight of the potato if it were completely dehydrated. A relationship has been found between the output of the dual energy x-ray absorption scanner and the amount of dry matter in potatoes. Potatoes may be graded for quality by the amount of dry matter with the potatoes having the highest percentage by weight of dry matter being the best quality. In another application the dual energy x-ray absorption scanner may be used to detect dirt or stones on potatoes or other root vegetables.

In summary, the method of the invention provides a non-invasive means for determining properties of a complex material such as coal or wool through calculation of the effective atomic number of the material. Determination of the effective atomic number of coal using this method provides a commercial advantage in that coal grading criteria can be improved, coal properties can be assured, all coal can be scanned providing instantaneous results at a lower cost than current systems.

The foregoing describes the invention including preferred forms thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated in the scope hereof as defined in the accompanying claims.

CLAIMS

1. A method for non-invasive assessment of a property or properties of a chemically complex material, comprising scanning the material with a dual energy x-ray absorption scanner and measuring the intensity of high and low x-ray beams after passing through the material, calculating an effective atomic number for the material, and assessing the property or properties of the material by reference to the effective atomic number calculated for the material.

2. A method according to claim 1 including comparing the calculated effective atomic number to stored data correlating effective atomic number to the property or properties of the material.

3. A method according to either one of claims 1 and 2 where the material passes continuously through the scanner and the effective atomic number is continuously calculated on-line.

4. A method according to any one of claims 1 to 3 including grading the material based on the calculated effective atomic number or the property or properties of the material.

5. A method according to any one of claims 1 to 3 including grading the material into one of at least two grades dependent on whether the calculated effective atomic number for the material is above or below at least one pre-set limit or threshold value.

6. A method according to any one of claims 1 to 5 wherein the material is coal.

7. A method according to claim 6 wherein the property is the composition of the coal.

8. A method according to claim 6 wherein the property is the ash content of the coal.

9. A method according to any one of claims 6 to 8 further comprising moving the coal past a radiation source which is effective to turn silicon into aluminium-28

and aluminium-27 into aluminium-28, detecting the level of gamma rays emitted by aluminium-28, and assessing the ash content of the coal.

10. A method according to any one of claims 1 to 5 wherein the material is wool.

11. A method according to claim 10 wherein the property is the amount of moisture in the wool.

12. A method according to claim 10 wherein the property is the amount of pure wool in raw wool.

13. Apparatus for non-invasive assessment of a property or properties of a chemically complex material, comprising a dual energy x-ray absorption scanner arranged to scan the material and measure the intensity of high and low x-ray beams after passing through the material, and associated processing means arranged to calculate an effective atomic number for the material and assess the property or properties of the material by reference to the effective atomic number calculated for the material.

14. Apparatus according to claim 13 wherein said processing means is arranged to compare the calculated effective atomic number with stored data correlating effective atomic number to the property or properties of the material.

15. Apparatus according to either one of claims 13 and 14 arranged to continuously assess the property or properties of the material on-line as the material passes through the scanner.

16. Apparatus according to any one of claims 13 to 15 together with associated grading means arranged to grade the material on-line.

17. Apparatus according to any one of claims 13 to 16 wherein the material is coal.

18. Apparatus according to claim 17 wherein the property is the composition of the coal.

19. Apparatus according to claim 17 wherein the property is the ash content of the coal.

20. Apparatus according to any one of claims 17 to 19 further comprising means arranged to move the coal past a radiation source which is effective to turn silicon into aluminium-28 and aluminium-27 into aluminium-28, detect the level of gamma rays emitted by aluminium-28, and assess the ash content of the coal.

21. Apparatus according to any one of claims 13 to 16 wherein the material is wool.

22. Apparatus according to claim 21 wherein the property is the amount of moisture in the wool.

23. Apparatus according to claim 21 wherein the property is the amount of pure wool in raw wool.

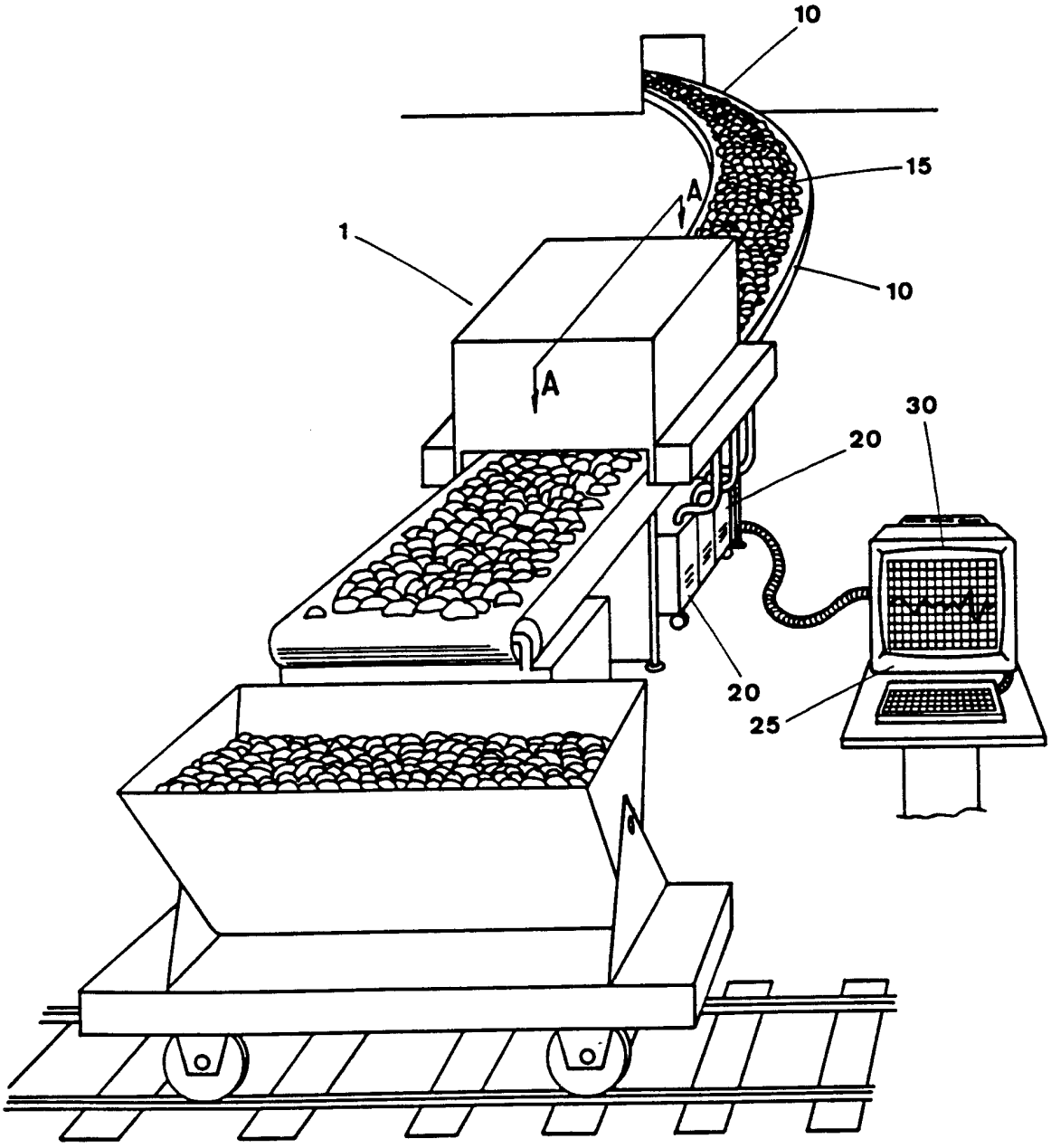


Figure 1

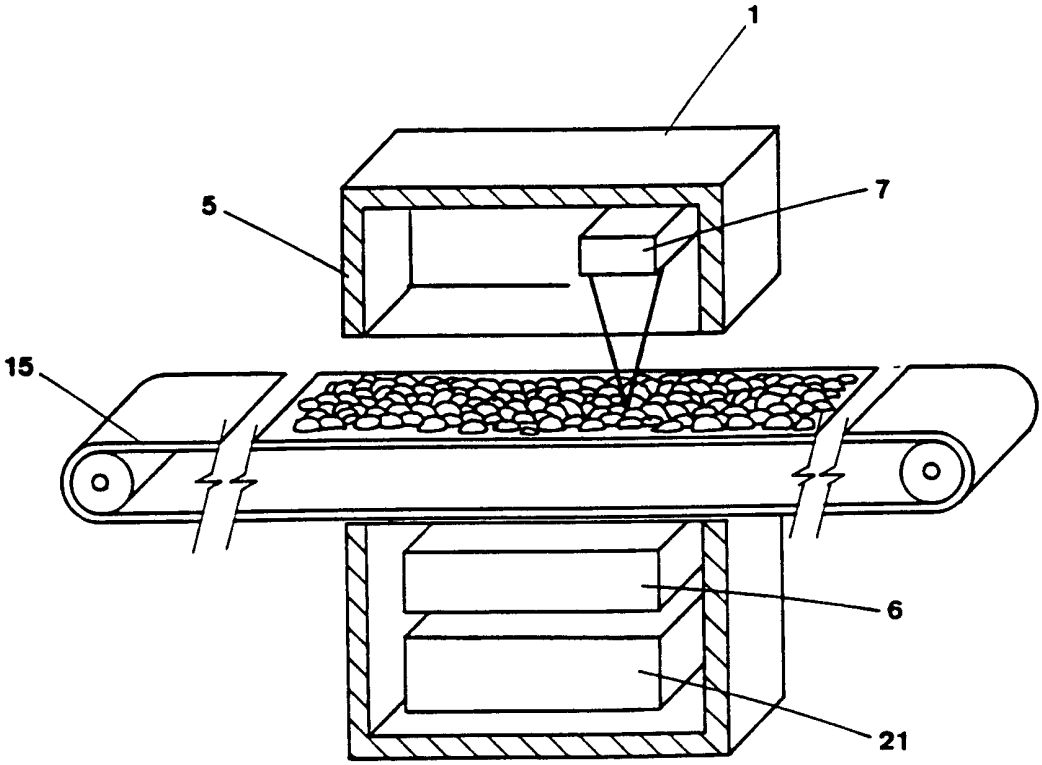


Figure 2

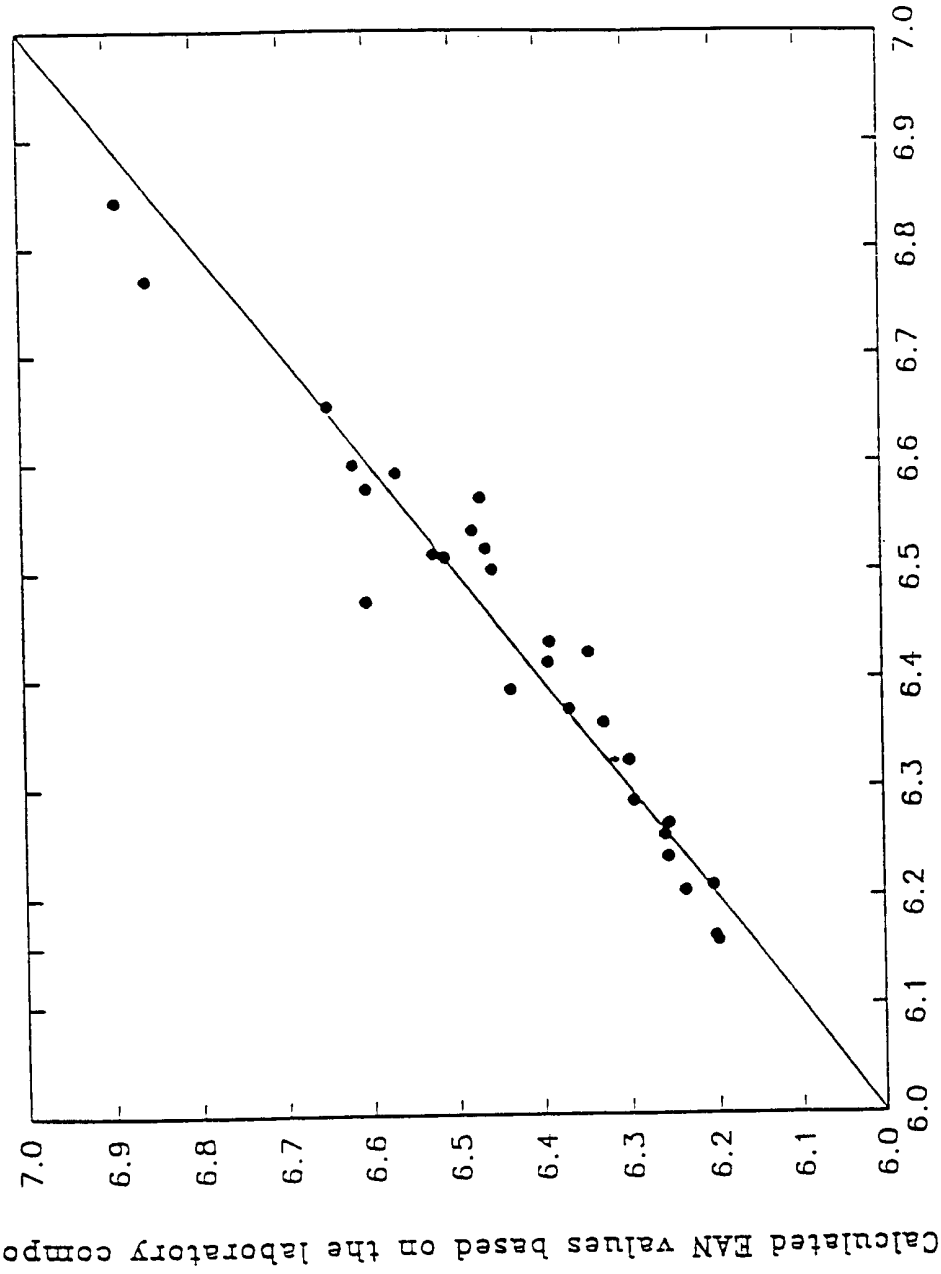

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6.3
6.4
6.5
6.6
6.7
6.8
6.9
7.0
Calculated EAN values based on the laboratory composition
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0

Figure 3

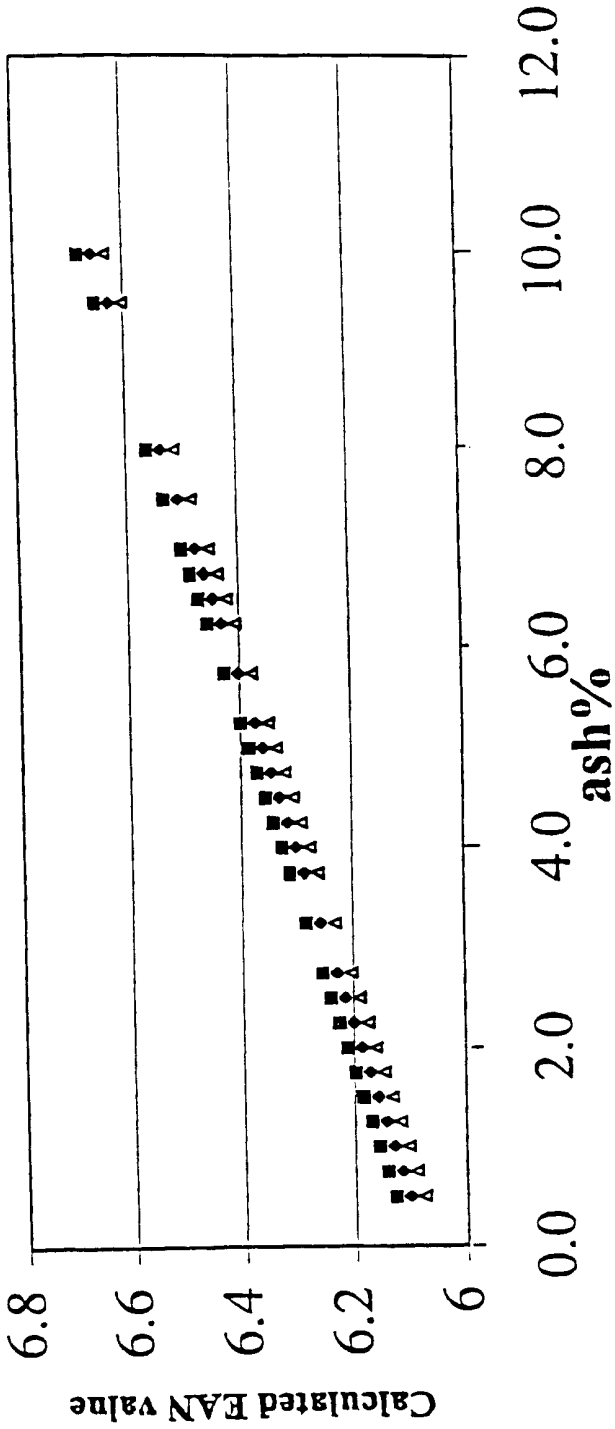


Figure 4

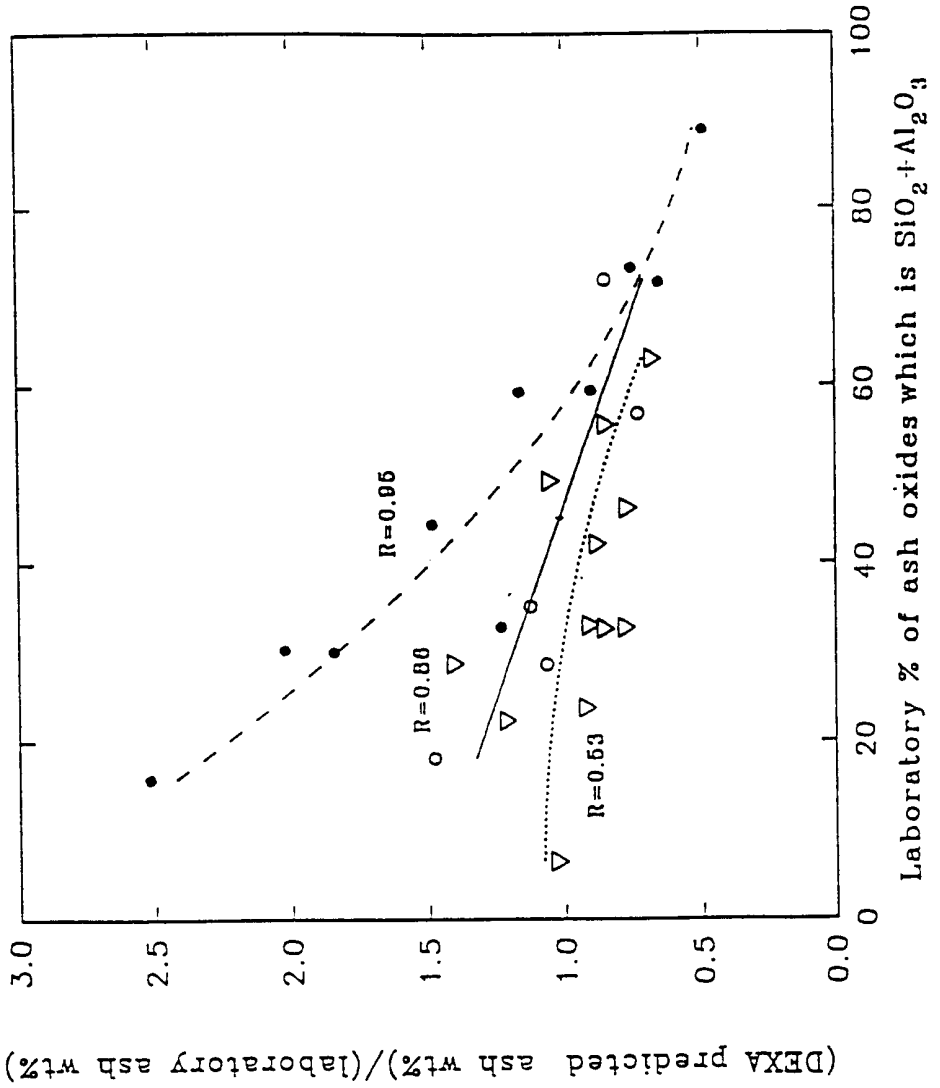

R=0.95
R=0.80
R=0.53
(DEXA predicted ash wt%)/(laboratory ash wt%)
Laboratory % of ash oxides which is $SiO_2+Al_2O_3$
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100

Figure 5

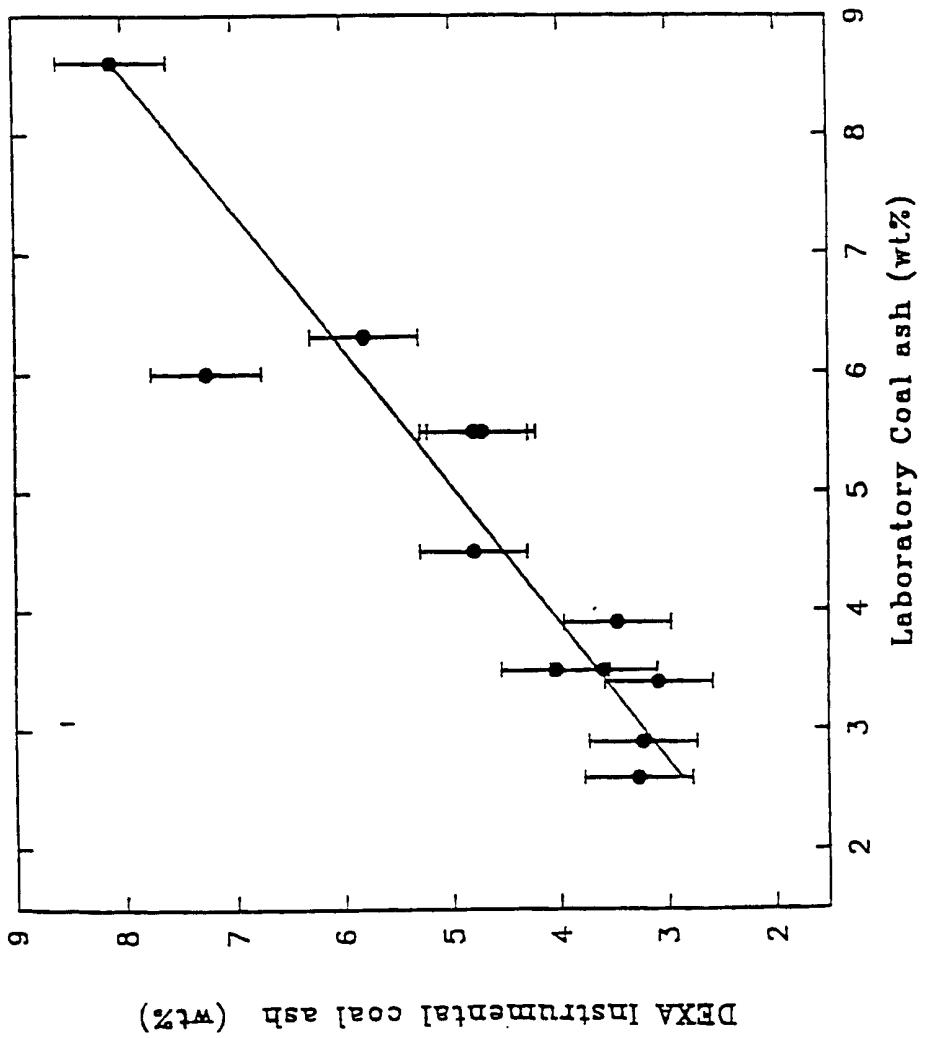

DEXA Instrumental coal ash (wt%)
Laboratory Coal ash (wt%)
2
3
4
5
6
7
8
9

Figure 6

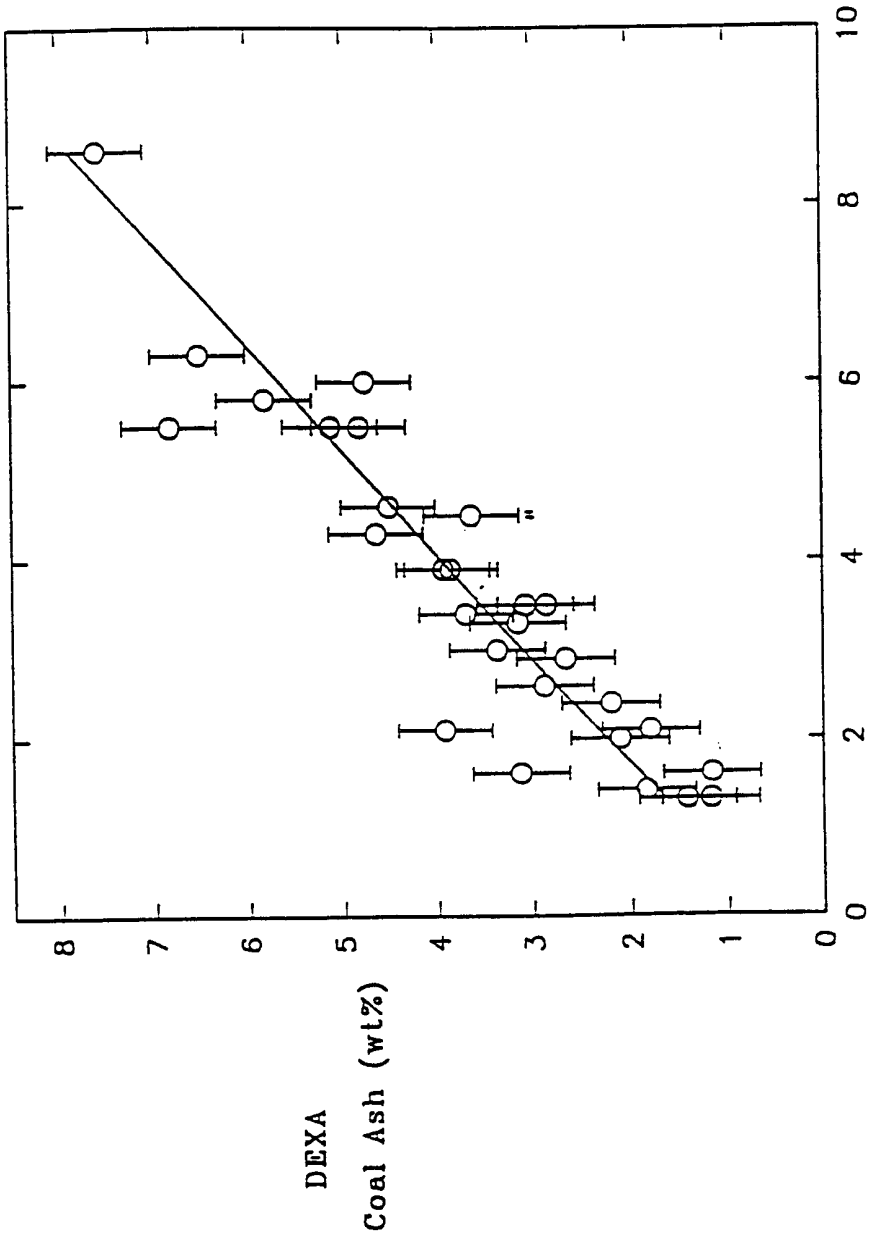


Figure 7

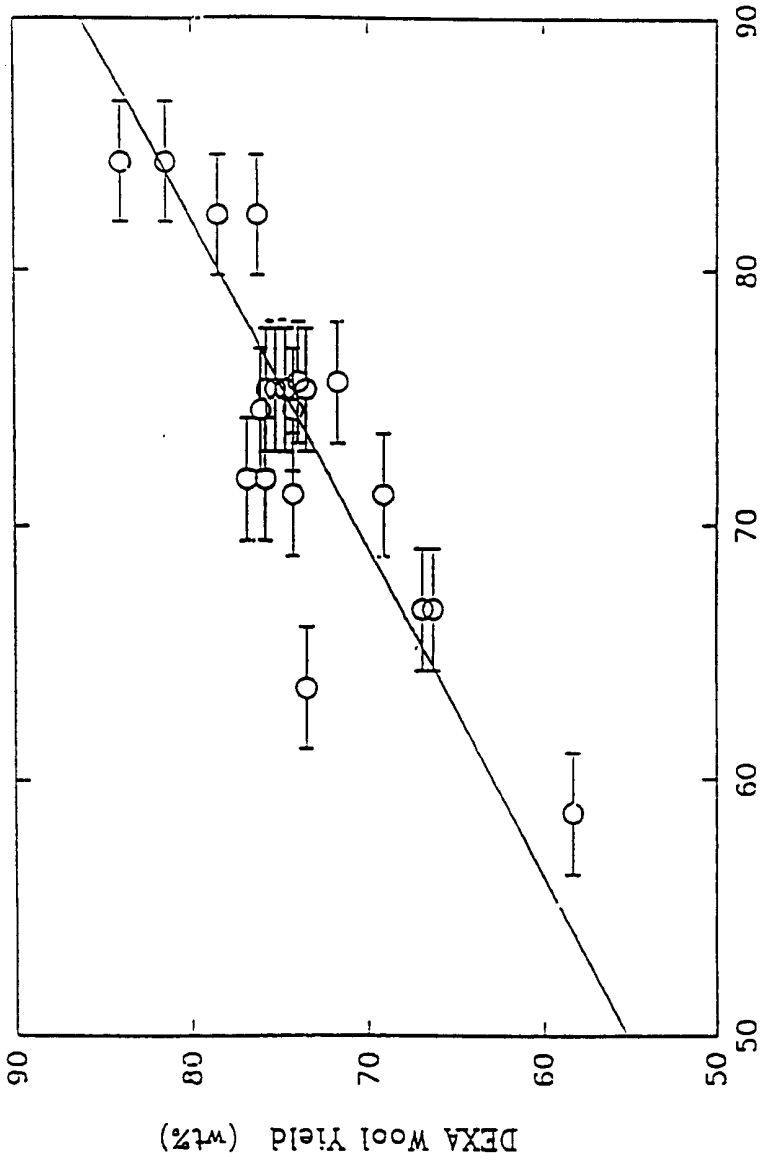


Figure 8

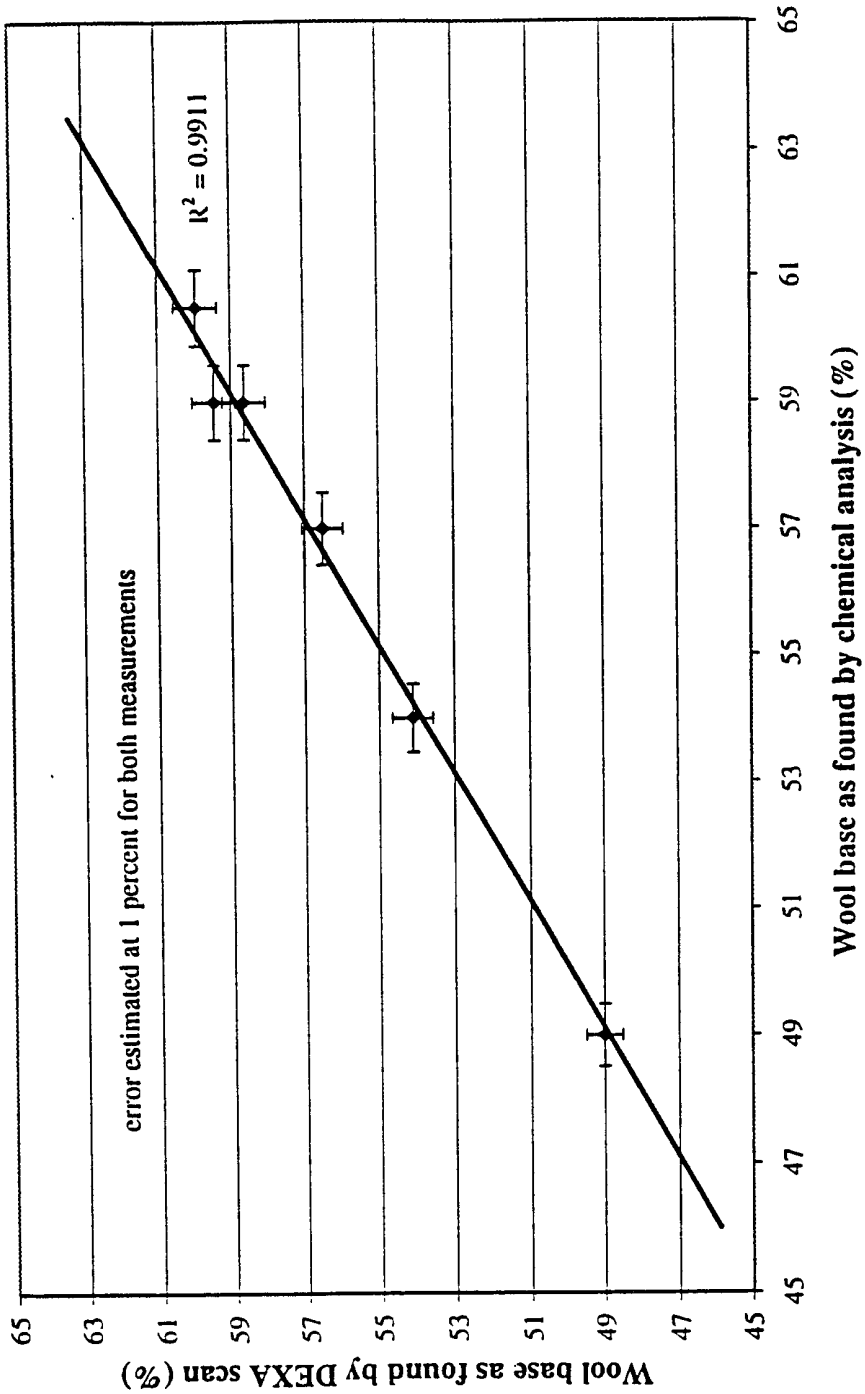

Wool base as found by DEXA scan (%)
Wool base as found by chemical analysis (%)
$R^2 = 0.9911$
error estimated at 1 percent for both measurements
65
63
61
59
57
55
53
51
49
47
45

Figure 9

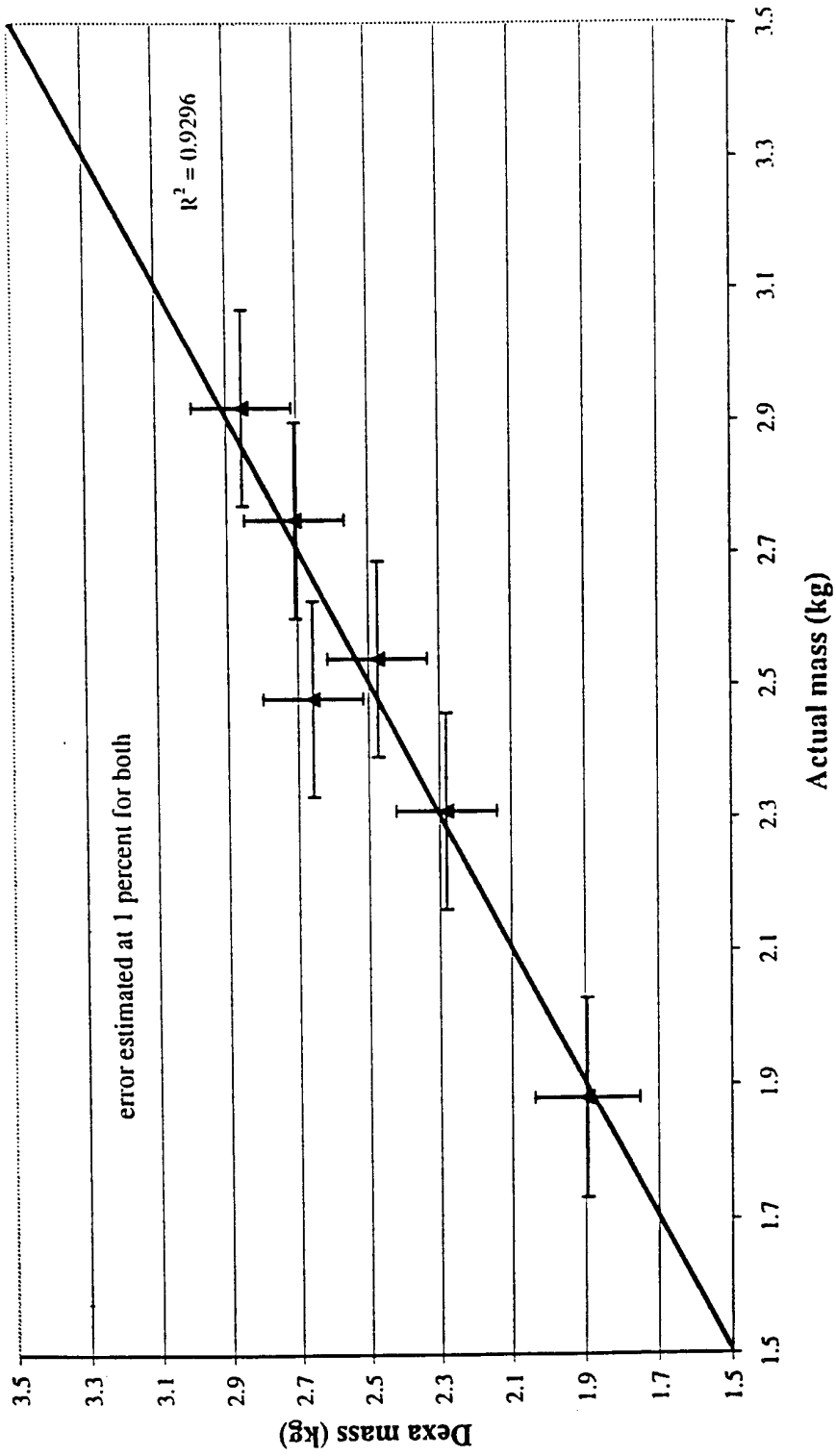

$R^2 = 0.9296$
error estimated at 1 percent for both
Dexa mass (kg)
Actual mass (kg)
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5

Figure 10

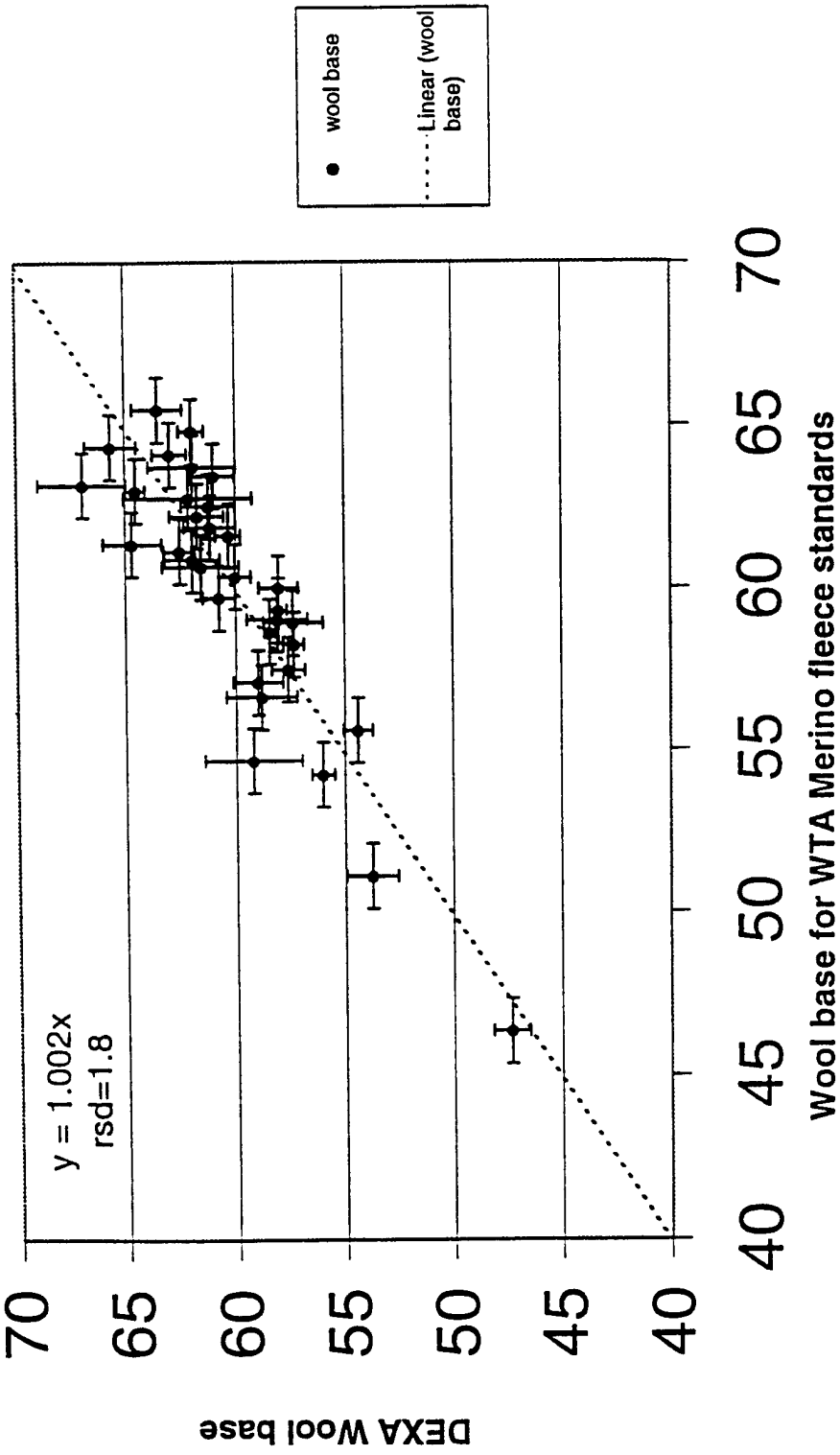

wool base
Linear (wool base)
y = 1.002x
rsd=1.8
DEXA Wool base
Wool base for WTA Merino fleece standards
70
65
60
55
50
45
40

Figure 11

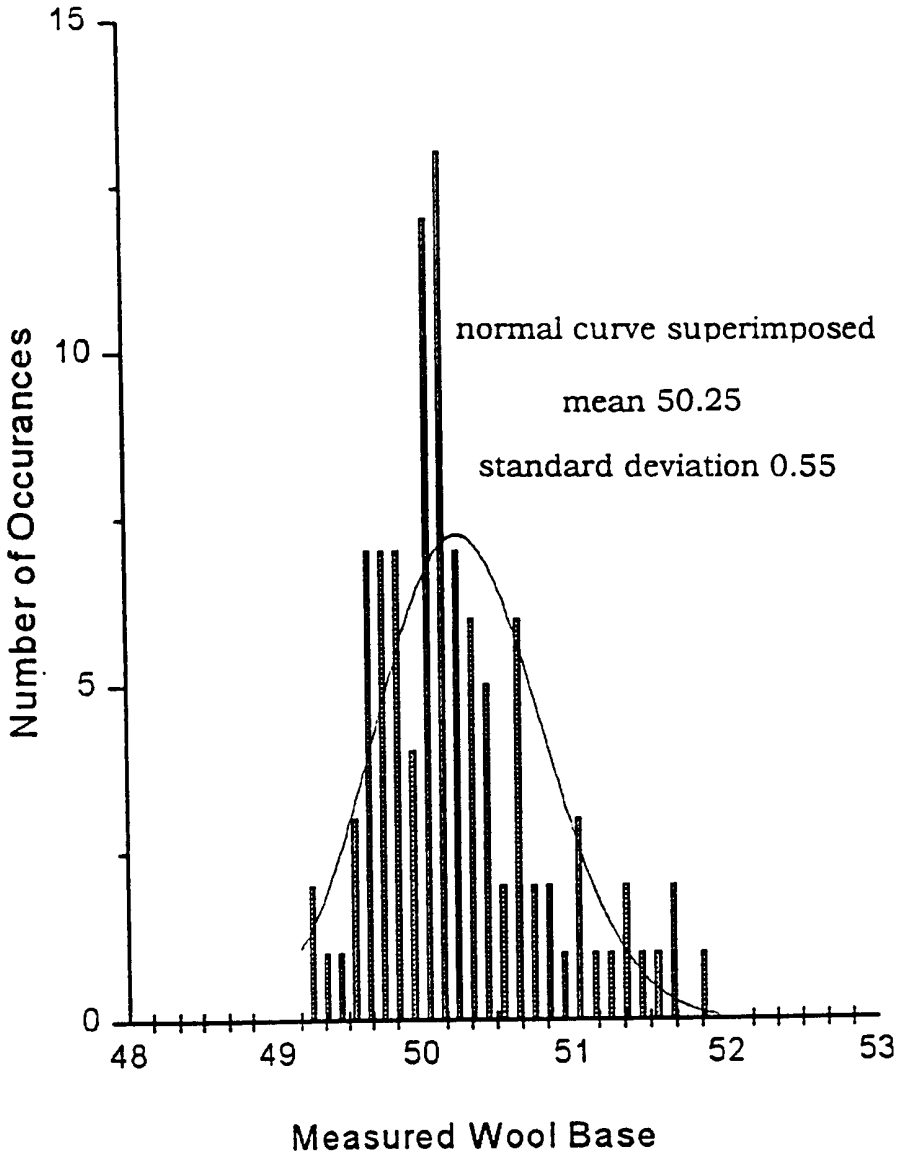

15
10
5
0
Number of Occurances
normal curve superimposed
mean 50.25
standard deviation 0.55
48
49
50
51
52
53
Measured Wool Base

Figure 12

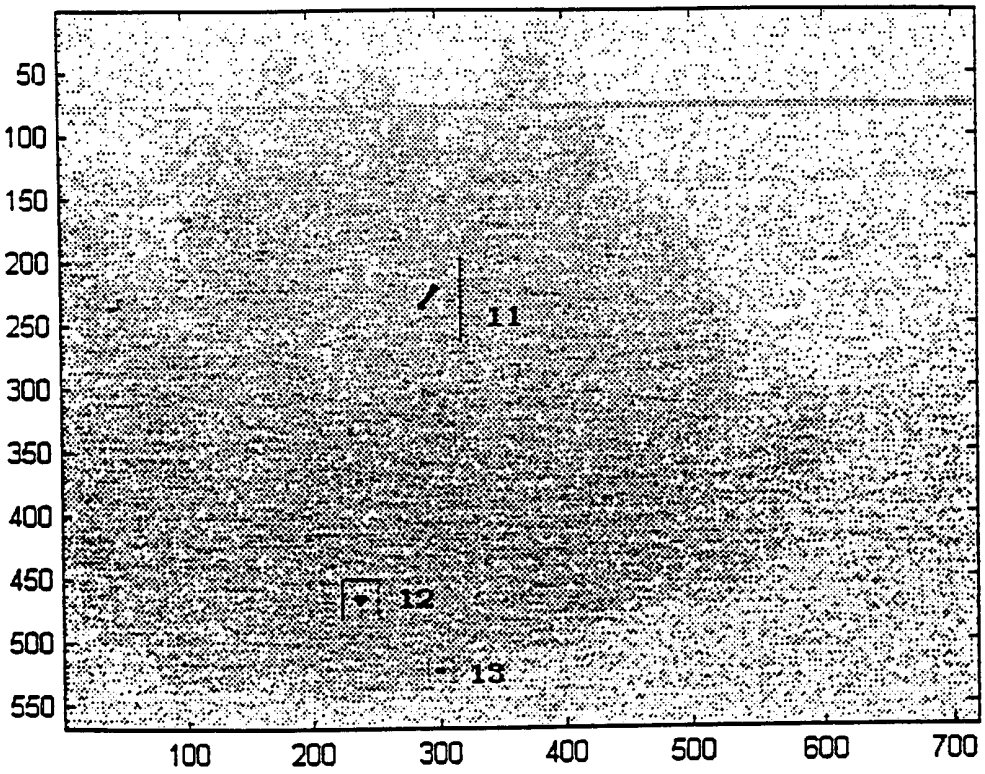

50
100
150
200
250
300
350
400
450
500
550
100
200
300
400
500
600
700
11
12
13

Figure 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ00/00144

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G01N 23/087

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G01N 23/087, 23/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU:IPC AS ABOVE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI and JAPIO: [x-ray+ or xray+] and [coal or wool] and absorb+ and [atomic [w] no or number] and (polyenergetic or dual + or two+ or high or low] () energ+)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/09400 A (EG &G ASTROPHYSICS) 25 February 1999	1-3,13-15
X	EP 141751 A (MEASUREX CORPORATION) 15 May 1985	1-3,13-15
X	US 4029963 A (ALVAREZ et al) 14 June 1977	1-3,13-15

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 November 2000	15 NOV 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ00/00144

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5044002 A (STEIN) 27 August 1991	1-3,13-15

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/NZ00/00144

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	99/09400	US	0609936	AU	87794/98	EP	1005640
EP	141751	AU	33673/84	DE	3478878	JP	60-129649
US	4029963	FR	2359595	GB	1589592	JP	53-017291
US	5044002	NONE					

END OF ANNEX