NON-INVASIVE MEASUREMENTS OF WOOL AND MEAT PROPERTIES

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Abstract: Recently strong progress has been made in the development of non-invasive measurement equipment and techniques for the in-line determination of raw wool and boneless meat qualities in industrial applications. Wool base is a measure of the matter that comprises the "real" wool, apart from grease, sheep gland excretions (called "suint"), water, and vegetable matter. In meat we investigate the chemical lean as a percentage, where the remaining percentage is attributed to fat. These qualities are important parameters which determine their commercial return value. The instrumentation is based on dual energy x-ray (DEXA) scanning and detection, where an image of the scanned object is created and subsequently analyzed without interrupting the process flow within the factory. In this technique, every pixel of the image provides data for a high and a low energy x-ray beam, where both x-ray energies result from single x-ray energy spectrum generation. In wool, we developed a method to determine the wool base in raw wool by evaluating and comparing both energies for every pixel and finding mean properties for the entire fleece. The method is very promising, and we expect industrial applications to be employed in the future. We also developed a method to determine the chemical lean in boneless meat that is packed in standard size meat boxes. This method is successfully installed in industry, scanning nearly continuously several thousand meat boxes each day. Single energy analysis can be successfully employed to scan wool or meat for contamination, which is also briefly discussed.

Introduction: The use of penetrating radiation, in particular x-rays, is significant in many areas of technology and medicine, and a useful overview can be found in [1]. Recently, rapid advance in computing technology has lead to powerful image analysis capability. This has been introduced into the animal based industries [e.g. 2]. Such technologies intend to improve or replace existing testing and evaluation methods that are presently often based on subjective impressions by individual evaluators. X-ray generated image applications use the absorption of x-rays by materials, which follow exponential absorption laws at specific energies. A typical arrangement of x-ray source, attenuating object, and x-ray detecting devices can be seen in Figure 1. As materials attenuate x-rays depending on their energy, use can be made of the selective attenuation of two or more x-ray energies, i.e., dual or multiple energy x-ray absorptiometry – DEXA or MEXA, respectively. DEXA allows the determination of material properties independently of their thickness by calculating the ratio of the attenuated x-ray beams. The ratio of the two x-ray energies can be calculated in various ways, most commonly as the so called log-ratio LR:

$$LR = \left. \log\frac{I_0}{I_L} \middle/ \log\frac{I_0}{I_H} \right. \quad , \qquad (1)$$

where I_0 is the non-attenuated incident x-ray energy, I_L is the attenuated x-ray energy of the low x-ray beam, and I_H is the attenuated x-ray energy of the high x-ray beam. The material can then be determined using the log-ratio of the image pixels of the object. While material attenuations are a collective sum of the effective atomic number (EAN) of the components [3], in practice the material composition calculations are based on calibrations with suitable materials, for instance Plexiglas.

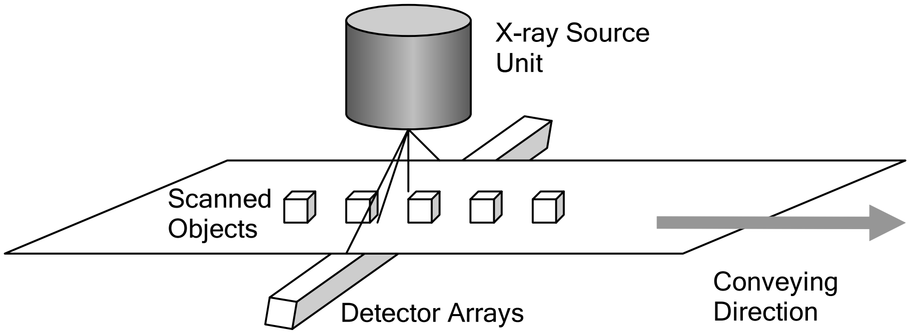

Figure 1. Arrangement of x-ray generating source unit, x-ray attenuating scanned objects, and detector devices for industrial applications. The position of detectors and source unit may also be reversed.

Two principal ways are possible to achieve two distinct x-ray energies; one uses two individual x-ray sources of specific energies and the corresponding detectors. The other method suffices with one x-ray source but filters the attenuated x-ray beam at the K-edge after detection at the low energy detector. This scheme is used in the arrangement of Figure 1, with the dual energy capable detector shown in Figure 2.

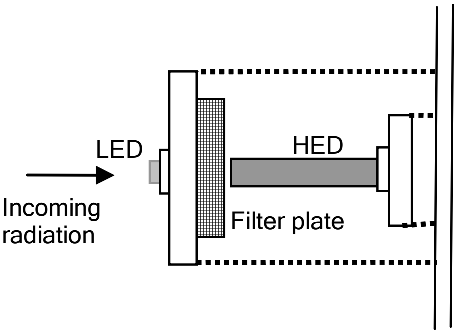

Figure 2. Dual energy capable detector. The incoming attenuated x-ray radiation is first detected at the low energy detector LED. The x-ray spectrum is then filtered at the K-edge of the filter material and the remaining spectrum, with a higher x-ray energy mean, is detected at the high energy detector HED.

DEXA has been used in medical applications for many years, such as for bone density and fat quantity estimations. Airport security scanners are also based on DEXA, which are capable of detecting anything from fruit and organic matter to explosives and weapons. Weapons and other objects made of dense metals may be detected using just single x-ray energy. As it will be shown later, such applications can have important and useful implications for industry.

Since the attenuation of an x-ray beam in the same material depends on its energy and on the thickness of the material; the optimum thickness of the material exists for every DEXA application for highest sensitivity. The difference between the magnitude of the attenuated high and low x-ray beam is a measure for the sensitivity and follows a distinct function, often referred to as the “banana” curve, shown in Figure 3. In this principal graph, which is here plotted for Plexiglas and lamb meat, the ordinate is the difference between the detected high and low energy beam, while on the abscissa the sum of it is drawn. Every point of the graph is the result of a certain thickness of the Plexiglas, with the thickest piece located near the origin, and steadily decreasing thickness with increasing sum of high and low beam. The maximum difference gives the optimum thickness of the scanned material and highest sensitivity. Every “banana” curve is distinct for a particular material and x-ray energies.

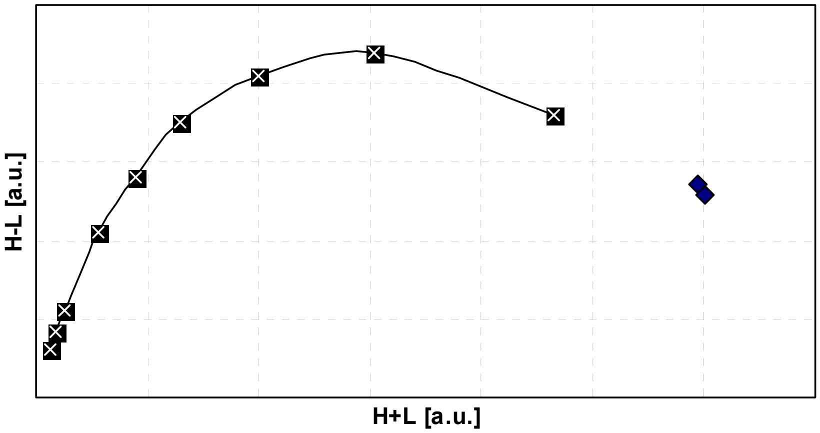

Figure 3. Dependence of the difference between the attenuated high and low energy x-ray beam on the thickness of the scanned object. The maximum in the curve shows the optimum thickness for the object of a certain material and x-ray energy. On the left hand side of the curve the sensitivity of the method decreases with increasing thickness, while to the right hand side the sensitivity decreases with decreasing thickness. The continuous curve is based on measurements of Plexiglas, a typical calibration material for muscle tissue, while the two individual points are measurements made with lamb meat, which are consistent with the overall plot.

DEXA applications have now been introduced to industry, a process which was delayed due to higher precision and accuracy demands at a very high speed [4]. Two industrial applications in the wool and meat industry for dual energy x-ray absorptiometry scanning will be presented in this article. Earlier research exposed meat and wool to other radiation probes [5,6,7], which had also been tested on other industrial products [8,9]. However, DEXA methods proved most successful, with several teams working on this technology today [4,10-13].

The most important quality parameter in the wool industry is the wool base or wool yield. This is the amount of pure wool after all additives such as vegetable matter, grease, and contaminations are removed from it. The wool base (WB) is determined according to the relation

$$WB = 100 - impurities(\%) \ . \qquad (2)$$

Impurities can include a wide range of materials, such as grease, grass, small stones, sweat-like material excreted by the sheep (“suint”), and other objects with which the sheep has contact. Due to the range of materials WB determinations may appear difficult, but DEXA tests have shown that good results can be achieved.

Traditionally, the wool base is determined by coring samples from a large amount of wool, mechanically removing all additives through washing and incinerating, and finally weighing the remaining ash, as a measure for the actual wool base. The laboratory method is highly labor and time intensive and carries the known problems of random sampling. DEXA is capable of determining the wool base non-destructively and in near real time. Each wool fleece is scanned and the DEXA x-ray image created, where an example is given in Figure 4. The term ‘DEXA image’ actually refers to two images at different mean x-ray energies, and the example in Figure 4 shows the low energy image. In the upper left quadrant a dark small spot indicates the presence of a stone in the fleece, a contaminant that may be difficult to detect with the naked eye. Image processing techniques can be used on single energy x-ray images to automatically detect these contaminants [14], a further important application for industry.

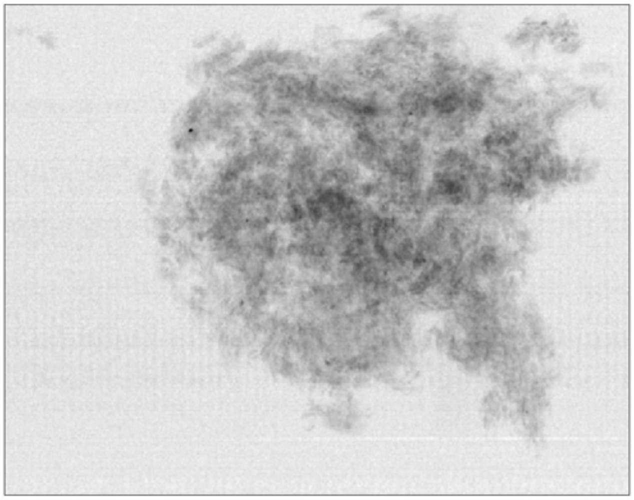

Figure 4. Low energy x-ray image of a sheep wool fleece. A small dark spot in the upper left quadrant shows the presence of a stone in the fleece.

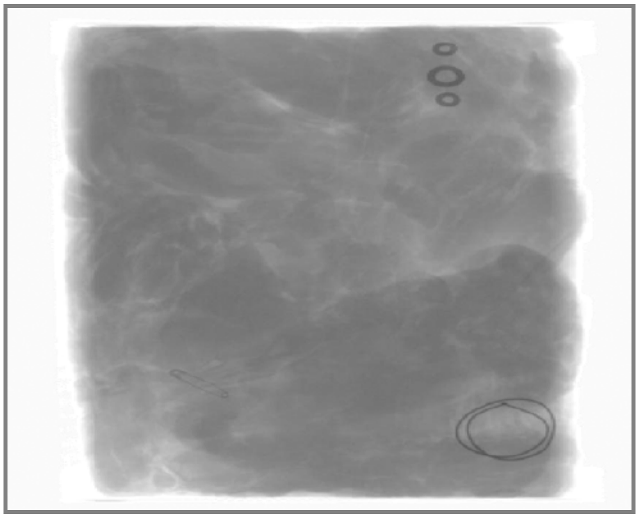

Figure 5. Low energy x-ray image of a meat container (27.2 kg New Zealand standard container). The image shows besides meat and fat also a range of contaminants, such as washers, wire, and a safety pin (lower left quadrant).

Substantial improvement of quality and process control can be achieved in the meat industry with the introduction of DEXA techniques. Laboratory testing is, as in the wool industry, lengthy and of random nature, while DEXA analyses every single product item instantly. The fast processing time allows excellent process control, for instance in the production of hamburger patties or sausages, where fast response and feed back can change meat properties swiftly. Similar to the wool base determination, the meat leanness, or chemical lean (CL), is determined as

$$CL = 100 - fat(\%) . \qquad (3)$$

Although boneless meat consists of chemically lean meat, fat, and muscle connective tissue, the latter can be ignored for these purposes. In Figure 5 an image of a cardboard container filled with boneless meat is shown. The illustration shows the low energy image. Besides the meat and fat in the box the image also shows various articles that are considered contaminants for the meat industry. These items, which were purposely placed on the container, are easily picked up visually from the image and can be detected automatically through image processing techniques, thus exceeding the capacity of commonly installed metal detectors in meat processing industries.

Results: Estimations of wool base and chemical lean have been performed using relations (1), (2), and (3). Regression analyses' on known materials lead to formulae that were used to determine comparable values representing wool base or chemical lean. In general the composition relation takes the form:

$$WB / CL = A \cdot f(r) + B \cdot f(r) + C \cdot f(r) + D \,, \qquad (4)$$

where A, B, C, D are constants determined from regression analysis, and *f(r)* is a function incorporating some relation of the detected high and low energy beam, for instance such as in (1). Then the results were compared to actual laboratory measurements (different laboratory measurements from the ones used for the regression analysis). Figure 6 shows a comparison of DEXA results for wool base calculations and laboratory measurements. At this point few test results are available and more research has to be performed using improved x-ray scanning technology and image processing techniques.

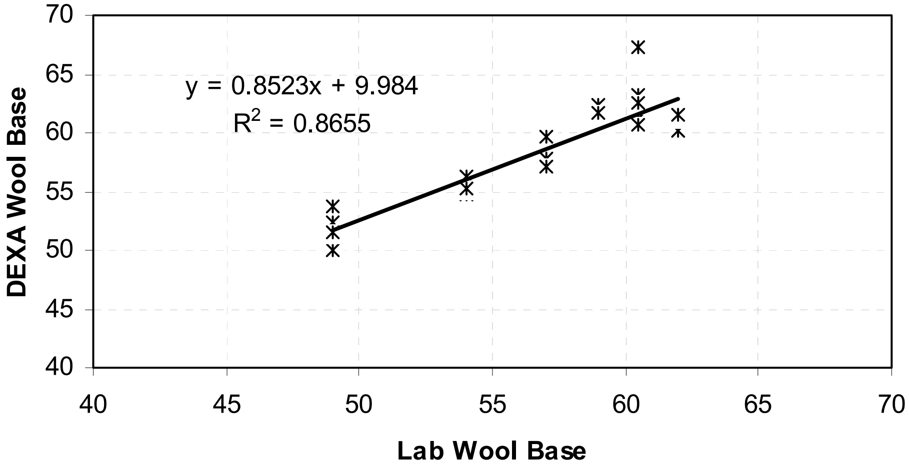

Figure 6. Comparison of DEXA wool base with lab measurements. The bold line is a linear trend line. Also given are the linear equation and the correlation coefficient R^2.

Better results were achieved for the comparison of DEXA with meat laboratory results. In Figure 7 the DEXA calculations were compared to the laboratory Soxhlet fat analysis of a homogenized meat box. The Soxhlet test is an accredited test, where a core is drilled out of meat and treated in such a way that results in a measurable volume of fat. The amount of fat found in the sample is considered correct for the entire container from which the sample has been taken, a valid assumption for the homogenized boxes. Homogenization is an important step in the comparison, as DEXA creates averaged results for the entire container, while daily production lab tests take cores out of untreated products and analyze them. In Figure 8 a similar comparison is performed with another laboratory test, the Babcock test. The Babcock test is not as accurate as the Soxhlet test, so the comparison with DEXA shows more variance.

Discussion: The introduction of a new method to measure a certain parameter is not always met by an established method to compare the new method with. This is the case with the introduction of DEXA measurements to replace traditional sampling and laboratory measurements. Traditional meat and wool testing involves random sampling, where samples often represent large quantities of product. DEXA methods deliver results for each produced item. Standards for wool base measurements or chemical lean are non-existent. Until the new methods are accepted, DEXA wool base results have to be compared with the weight percentage of the ash of the additive free wool. For the meat, it means comparing DEXA results with the Babcock or Soxhlet test, each of which shows discrepancies between the test performed on a regular meat production box, or on a homogenized meat box, which better reflects an average of the container. The difference between Babcock lab results for the normal production box and the homogenized meat box is shown in Figure 9, where rather large differences between the measurements can be seen. The comparison has been performed on the same meat box, where cores were first taken from the production box, followed by homogenizing the remaining portion and testing again. It should be noted that generally the Babcock test is considered the less accurate test method of the two fat testing tests.

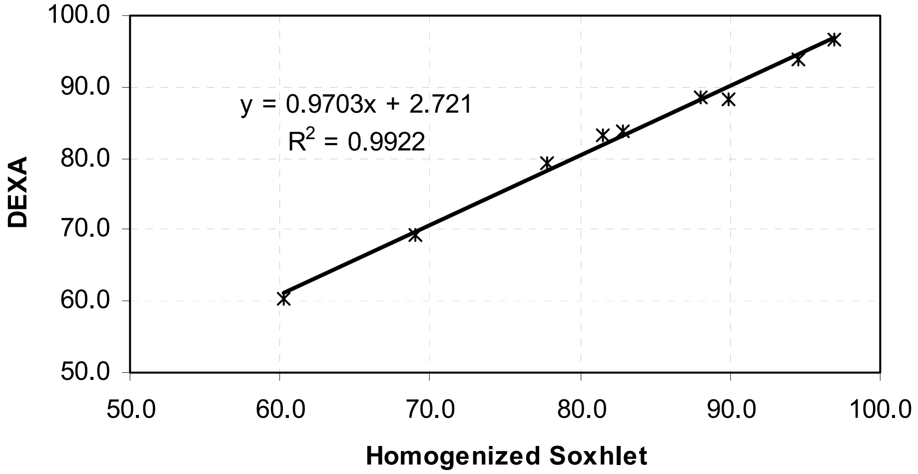

Figure 7. Comparison of DEXA chemical lean with Soxhlet lab measurements. The bold line is the linear trend line. The correlation coefficient R^2 reveals a very close correlation between DEXA values and the homogenized lab measurements.

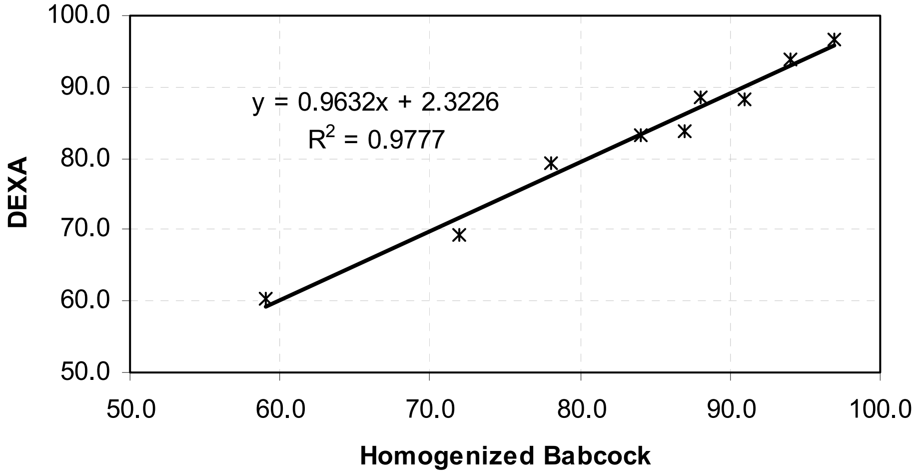

Figure 8. Comparison of DEXA chemical lean values with homogenized Babcock lab measurements. The bold line is the linear trend line. Here R^2 shows good correlation between the two methods, but lower than for the Soxhlet comparison.

In a much cited paper, Bland and Altman [15] discuss statistical methods that may be used to assess agreement between a new method and an established, yet not accurate method. Here we applied one of their suggested methods in an analysis of a large number of production boxes, which had been measured with DEXA analysis as well as with Babcock tests. DEXA measurements had been repeated once and the mean of these measurements calculated. The ordinate in Figure 10 is now the mean of two DEXA measurements, while the abscissa shows the average between the Babcock test and the mean DEXA value. If available, the average of several traditional test methods can be used, i.e., the Soxhlet and the Babcock test, but no Soxhlet results were available for the analysis. The result shows a reasonably good correlation between the measurements, although care should still be taken in comparing results of this different nature.

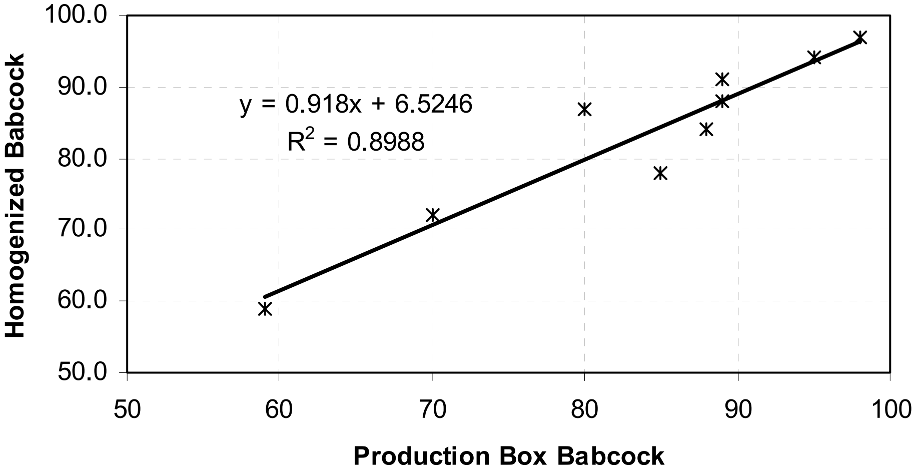

Figure 9. Babcock fat analysis results of the same 27.2 kg boneless meat box before and after homogenization. The solid line is the linear trend line of the individual measurements.

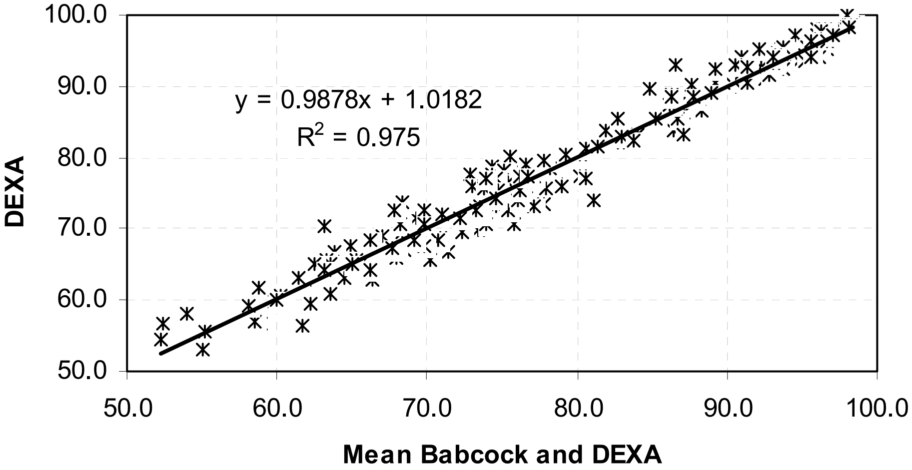

Figure 10. Comparison of DEXA and Babcock chemical lean results for standard non-homogenized meat boxes, taking into account statistical methods as suggested by Bland and Altman [15]. The correlation is considerably better than comparing directly DEXA and Babcock measurements.

Conclusions: New quality control methods that meet the increasing demand from world markets for standardized products in the animal based industry are presented. Introduced methods are based on DEXA, an established technique in medicine, but that is now able to perform accurate measurements at a very high speed and mainly fully automated. A further condition to successfully introduce DEXA methods into industry is that abrasive, often humid and even wet conditions must be tolerated by the technology. Two measurement methods based on DEXA to determine the fat content of boneless meat and the wool base of wool fleeces were presented. No absolute standard techniques to measure either quality exist; therefore comparisons with traditional established methods are difficult and possibly misleading. While traditional methods rely on sampling with a relatively large error, DEXA can provide measurements for each produced item and for the entity rather than a sample. Results show that the new techniques can be successfully employed in these environments, and, although comparable data is in short supply, the outlook for these techniques is very optimistic. Industry can be provided with a technique that sets new standards on measurement techniques without sampling.

References: [1] Hussein E.M.A., Handbook on radiation probing, gauging imaging and analysis, Kluwer Academic Publishers, Dordrecht, 2003, 464 pp.

[2] J. Tan, Meat quality evaluation by computer vision, *J. Food Eng.*, *61*, 2004, 27-35.

[3] Johns H.E., Cunningham J.R., The Physics of Radiology, Publisher C.C. Thomas, 1983, pp 241.

[4] C.M. Bartle, C. Kroger, J G West, New uses of x-ray transmission techniques in the animal-based industries, *Radiation Physics and Chemistry*, accepted for publication January 2004.

[5] Bartle C.M., Simultaneous transmission of neutrons and gamma rays (neugat) to measure fat in meat. Appl. Radiat. Isot. 42, 1991, 1115-1116.

[6] Bartle C.M., Features of the measurement of fat in meat using the neutron/gamma transmission (neugat) method. *Appl. Radiat. Isot.,* 1995, *46*, 741-750.

[7] Bartle C.M, Comparison of the response of raw wool to simultaneous neutron and γ-ray (neugat) transmission and simultaneous dual energy γ-ray (gamgat) transmission, *Appl. Radiat. Isot.*, 50, 1999, 859-866.

[8] Bartle C.M., Measurement of the composition of dairy products using the neutron/gamma transmission (neugat) method. *Appl. Radiat. Isot.*, *45*, 1994, 1039-1045.

[9] Bartle C.M., Measurement of the composition of some liquid mixtures using the simultaneous transmission of neutrons and gamma rays (neugat) method. *Appl. Radiat. Isot., 47*, 1996, 739-744.

[10] GNS, A method for the non-invasive measurement of the properties of meat, NZ Patent No. 502033, 1999.

[11] PCT International Patent Application No. PCT/NZ01/00108, A method for the non-invasive measurement of properties of meat, 2001.

[12] Hansen P.W., Tholl I., Christensen C., Jehg H.C., Borg J., Nielsen O., Ostergaard B., Nygaard J., Andersen O., Batch accuracy of on-line fat determination, *Meat Science*, *64*, 2002, 141-147.

[13] J. P. Brienne, C. Denoyelle, et al., Assessment of meat fat content using dual energy X-ray absorption. *Meat Science 57*(3), 2001, 235-244.

[14] C. Kröger, C.M. Bartle, J.G. West, and V.-H. Tran, Digital x-ray imaging and image processing for object detection in closed containers, Trans. CGIM04, Kauai, Hawaii, USA, 2004.

[15] J.M. Bland and D.G. Altman, Statistical methods for assessing agreement between two methods of clinical measurement, *Lancet*, 1986 ; **i:** 307-310.