# final report

Project code: A.TEC0066

Prepared by: David Miljak

CSIRO

Date published: May 2009

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

## Evaluation of an on-conveyor sensor for measuring chemical lean in meat trimmings

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

# Abstract

Configuration of a CSIRO laboratory prototype sensor potentially suited to the measurement of chemical lean (CL) in meat trimmings on conveyors has been completed. The sensor size is compatible with conveyors used in meat processing applications. The sensing volume also contains a non-conducting sheet used to simulate flat plastic conveyors used in the meat processing industry. Initial tests on simple meat simulant samples confirm signal detection in the sensor.

While the CSIRO sensor has a very homogeneous response across a large volume, and is sensitive to relatively small trimming size, the variations in trimming *shape* that are likely to occur in a real application has caused problems with obtaining a linear response from the sensor. Attempts were made to linearise the response by changing the dimensions of the sensor, the configuration of active elements in the sensor, as well as excitation frequency. Unfortunately, in all cases studied, the variations due to shape differences will ruin the correlation to CL that needs to be established for use in online control. This report describes the measurement problems encountered for variable sample shape, the reasons for failure of the CSIRO sensor configured for this application and a description of the generic problems likely to affect a range of different electromagnetic methods for measuring CL in trimmings.

Based on the outcomes of Milestone 2, CSIRO recommends that Milestone 3 not be pursued.

**Contents**

# 1 Milestones

1. Configuration of a lab prototype sensor utilizing an existing CSIRO Sensor particularly suited for meat conveyor application. This involves configuring a sensor of suitable size, compatible with typical conveyor dimensions, positioned inside a metal enclosure with geometry consistent with the CSIRO Sensor concept. The general conveyor arrangement is simulated with non conducting sheets of synthetic material, positioned inside the sensor volume, upon which test samples are placed.
2. Optimising CSIRO sensor configuration, involving electrically testing the sensor to optimise CSIRO sensor homogeneity.

# 2 Project objectives

The Project is intended to determine whether a CSIRO CL (Chemical Lean or fat/lean content) measurement sensor for on-conveyor loose meat trimmings is feasible, technically and economically. The project will focus on the potential of lower radio frequency technology to provide a solution. Specific objectives include:

- Confirm operation of the CSIRO Sensor in realistic size and geometry.
- Confirm sufficient sensitivity of the CSIRO Sensor to the range of trimming sizes.
- Confirm adequate uniformity of the CSIRO Sensor response for different position of presentation inside the sensor volume.
- Confirm sensitivity of the CSIRO Sensor to CL variation typically found in processing operations e.g., 65-95%CL, for variable mass and presentation.
- If testing is successful, develop a design brief for a plant trial device that may be the subject of future work under a separate agreement.

# 3 CSIRO Sensor

Fig. 1 shows the CSIRO sensor at the CSIRO Minerals Lucas Heights radio frequency laboratory, specially configured for the particular CL measurement application, while Fig 2 shows schematically the measurement zone and sensor dimensions.

The sensor is enclosed in a metallic shell around the top, bottom and two sides, but is open on the two remaining opposing sides to allow for the ingress of the conveyor structure that would obviously occur in actual installations. The CSIRO sensor itself is composed of two measurement and detection layers containing metallic elements, located towards the top and bottom of the enclosure. These sensor layers are supported by sheets of insulating material (perspex, 10mm thick). The lower sensor layer is also covered with an additional layer of perspex. In the current prototype configuration the metal components of the sensor and enclosure are constructed from copper. However, in a final implementation that may be the subject of future development (under a separate agreement), the metal components may be constructed of food-grade stainless steel, and all insulating sheets from food-compatible plastics. (From previous work, the performance of the sensor is not strongly dependant on construction materials for these components.)

To account for the plastic conveyor normally encountered in applications, an additional Perspex sheet is suspended a few centimetres above the lower sensor layer. This dimension may be varied as part of future work. In addition, the separation of sensor layers may also be varied.

Metallic elements in the sensor are electrically driven with a radio frequency signal (megahertz range), and other elements are used to detect the response of the material located in the sensor zone. The response is dependent on the electrical properties of the material under test. The work proposed under future milestones of this project aims to ultimately test the correlation between CL in meat trimmings and electrical properties as measured by the CSIRO sensor.

Initial measurements have been performed using small samples simulating meat trimmings (containers of various shapes filled with salted water). Signal deflections have been observed, consistent with the expected output from the CSIRO sensor. Work is now underway on Milestone 2, which involves attempted optimisation of the sensor to provide sufficient sensitivity for useful CL detection.

## 3.1 Principle of Operation

The principle of operation of the CSIRO sensor involves establishing a highly uniform electric field between two sensing planes at frequencies < 14MHz. The sensor measures the RF displacement current flowing between the planes. Insertion of a material with high dielectric constant between the planes leads to a lowering of the electrical impedance between the planes. This occurs because of the electric polarisability associated with a given sample i.e., a change in charge distribution is induced in the sample by the electric field. This change manifests itself as an increase in detected displacement current between the planes. This current can be detected rapidly. The sensor must be configured for stability and sensitivity to small masses of material. It must also be configured for insensitivity to other currents flowing to RF shields or nearby objects. The CSIRO sensor is capable of measuring both real and imaginary parts of the response i.e., both effects related to the value of the dielectric constant *and* dielectric loss. Dielectric loss is the electrical loss associated with inducing the polarisation in the sample.

For the analysis of meat trimmings, it is expected that the non-fat components (both “free” water and protein macromolecules) will most strongly contribute to the bulk dielectric constant at the frequencies used. It is therefore expected that the response may correlate to the non-fat components, and hence ultimately to the CL level in a given trimming.

**Figure 1.** CSIRO laboratory prototype CL sensor configured at CSIRO Lucas Heights Radio frequency laboratory. The view is along the direction the conveyor would normally run in actual applications. Sensor layers are visible towards the top and bottom of the enclosure. A perspex sheet serves to simulate the conveyor.

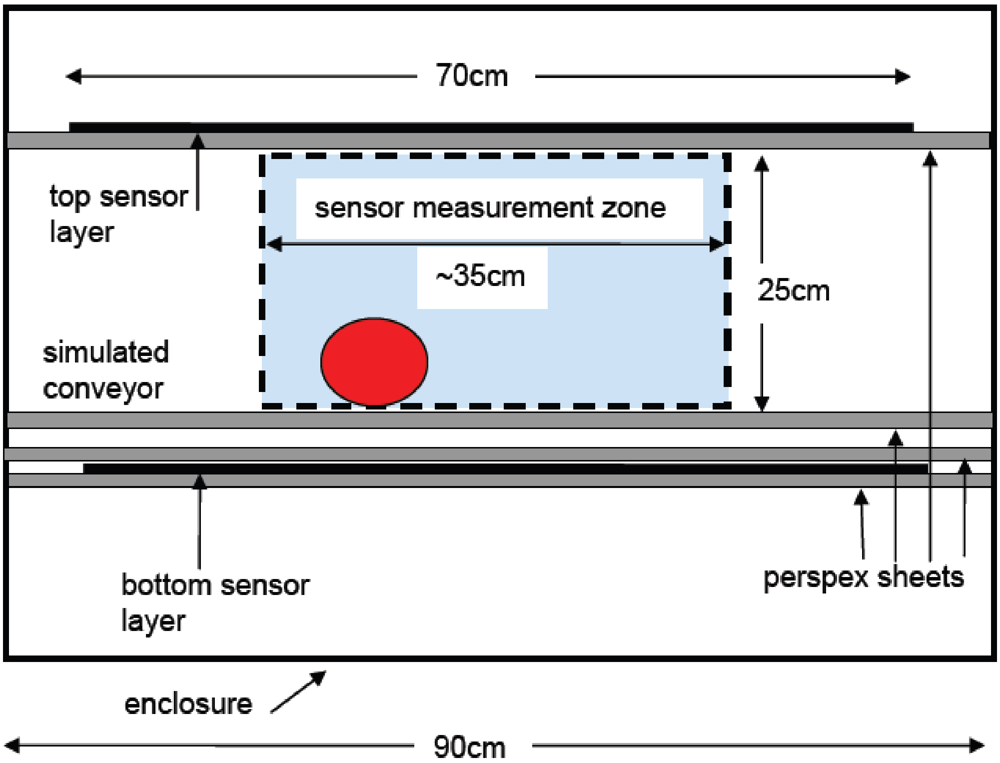


**Figure 2.** Sensor geometry and dimensions (viewed down conveyor). Not to scale.

# 4 Method and Results

## 4.1 Selection of appropriate trimming simulant

Owing to the amount of work required in presenting different samples, suitable simulants for meat trimmings were required for routine and repeated measurements performed over long periods. To develop a suitable simulant, a small sample of lean mince meat (500mL sample) was first obtained and presented to the sensor by placing it in a lightweight plastic container. The plastic container, having low mass and dielectric constant, made only a very small contribution to the overall response. This was confirmed through separate measurements on the container alone. The minced meat response was then compared to the response obtained from the same mass of tap water in the same type container, but the water slightly salted to mimic the same levels of conductivity typical of meat samples. It was found that the meat sample provided response almost as strong (95%) as the tap water samples, the comparison being reproducible over several different container shapes. To mimic the effect of fat nodules or layers, insulating plastic blocks or sheets were inserted into the containers.

## 4.2 Sensor test work

For online analysis of meat trimmings, the sensor must exhibit the following properties:

- Good measurement homogeneity i.e., the sensor must be robust to changes in trimming position across the conveyor.
- Adequate sensitivity, i.e. accuracy must be maintained for trimming sizes at lower mass range.
- Adequate accuracy over variable trimming shape.

The required accuracy for each trimming may be determined from the target accuracy required for on line control of CL in 27kg cartons. The project objective was to develop a sensor with sufficient accuracy to control addition of CL in a carton to within a 5% band. That is, CL for trimmings must be measured continuously to build up an estimate of carton CL with +/- 2.5% accuracy. Each carton is composed of many loose trimmings and consequently, to obtain the required 2.5% accuracy, the accuracy for individual trimmings may be relaxed. The accuracy limit required for each trimming is approximately given by 2.5wt% times the square root of the number of trimmings per carton. If it is assumed that 30 trimmings make up a carton, then the measurement precision for each trimming must be less than approximately 13wt%. Of course, the trimming CL estimates must also be unbiased.

**Therefore, the combined inaccuracy relating to sensor homogeneity, sensitivity and trimming shape must not exceed more than ~13wt%.** As will be demonstrated below, errors relating to homogeneity and sensitivity are well below this error, but shape effects cause the sensor to significantly exceed the indicative limit outlined above. The performance of the CSIRO sensor with respect to sensor homogeneity, sensitivity and sample shape is outlined below.

## 4.3 Measurement Homogeneity and Sensitivity

As a test of sensor homogeneity, a 300g sample of trimming simulant (placed in a cylindrical plastic container, with diameter 97mm) was presented to the sensor at different positions across the simulated conveyor and at different vertical displacements. This is probably a relative small mass for a trimming, but this size was selected to test worst case uniformity and sensitivity limits.

The configuration of the CSIRO sensor was determined after some experiments with sensor segmentation and plane position. Fig. 3 shows a plot of typical sensor response versus sample position across the simulated belt. In all cases tested, the response varies only very little in the central regions, but rapidly deteriotes past a certain limit. However, there remains a large measurement zone where the response varies only by a very small amount. For a 40cm zone, the relative variation is only 3%. Vertical variation showed a similar variation for a 15cm range above the simulated conveyor. The smaller vertical range is expected to be less of an issue than the horizontal range limit, since it is expected that most trimmings will present entirely under the vertical range quoted above.

The stability and sensitivity was assessed by repeat measurements of the same sample in the sensor, carried out over several hours. For 200g samples, the variation was of the order of several percent. Higher sensitivity was obtained by placing the sensing planes closer together, at the cost of reduced homogeneity in the vertical direction. Trimming sizes are expected to be typically larger than 200g, so that these sensing errors are expected to be maximum values.

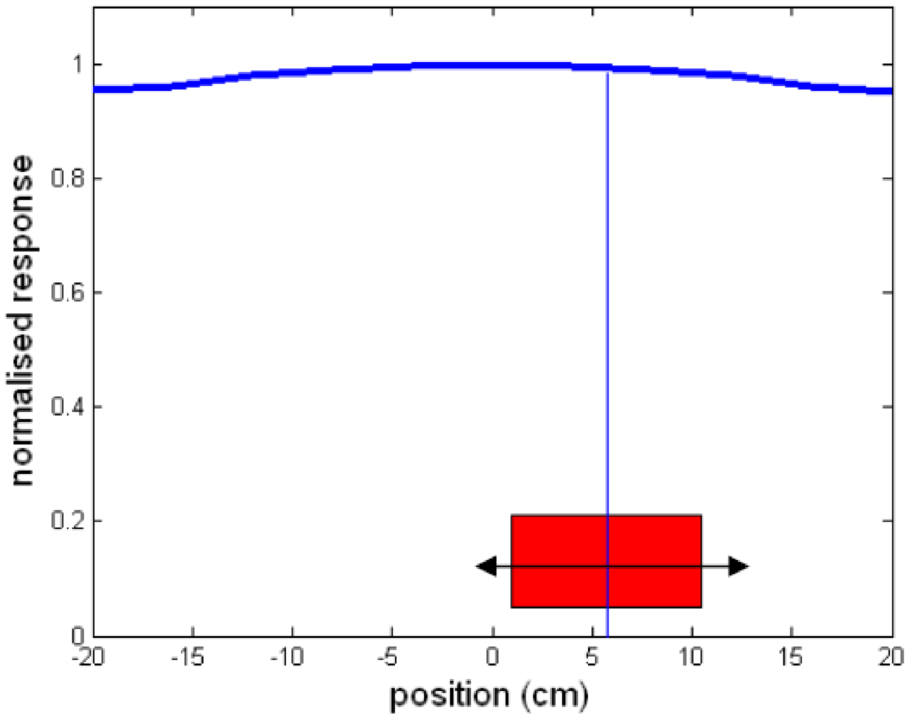


**Figure 3.** Typical response of CSIRO laboratory prototype CL sensor across the simulated conveyor. The 300g trimming simulant sample was placed at varying positions across the simulated conveyor, and response measured for each position.

## 4.4 Effects due to Variable Presentation

The effect of sample shape was initially assessed by presenting to the sensor simulants of the same mass, but different shapes. A range of cylinders with different heights h and diameters D were selected to provide shape variation. For each cylinder, the aspect ratio A = h/D may be defined. It was initially found that large area samples with low height (small A) had weaker response than small area samples with larger height (large A), despite the same mass. In the range A = 0.15 to A = 1.5, the response varied by over a factor of two, greatly exceeding the accuracy requirement discussed in the previous sections. Even for relatively small ranges of A, the discrepancy remains significant with respect to accuracy requirements. The strength of this variation was surprising.

To elucidate the cause of the variation, three fixed sample heights of 20mm, 40mm and 58mm were chosen for analysis. For each height, different sample areas were presented to the sensor. The results are shown in Fig. 4. A striking feature is the variable offset in response for each curve. If this offset is neglected, each curve actually demonstrates good linearity with changing sample area (which, for each curve, is proportional to sample mass). In this regard, the CSIRO sensor may be suitable for analysis of reproducibly shaped samples with known mass. However it is clear that variable offsets of the type shown in Fig. 4 will strongly influence the prediction of CL in trimmings with variable shape. For example, if a value is selected on the horizontal axis representing a given area, the response varies in non-linear fashion across the heights corresponding to that area. The non-linearity is especially evident at small sample mass, but persists at unacceptable levels at larger sample mass.

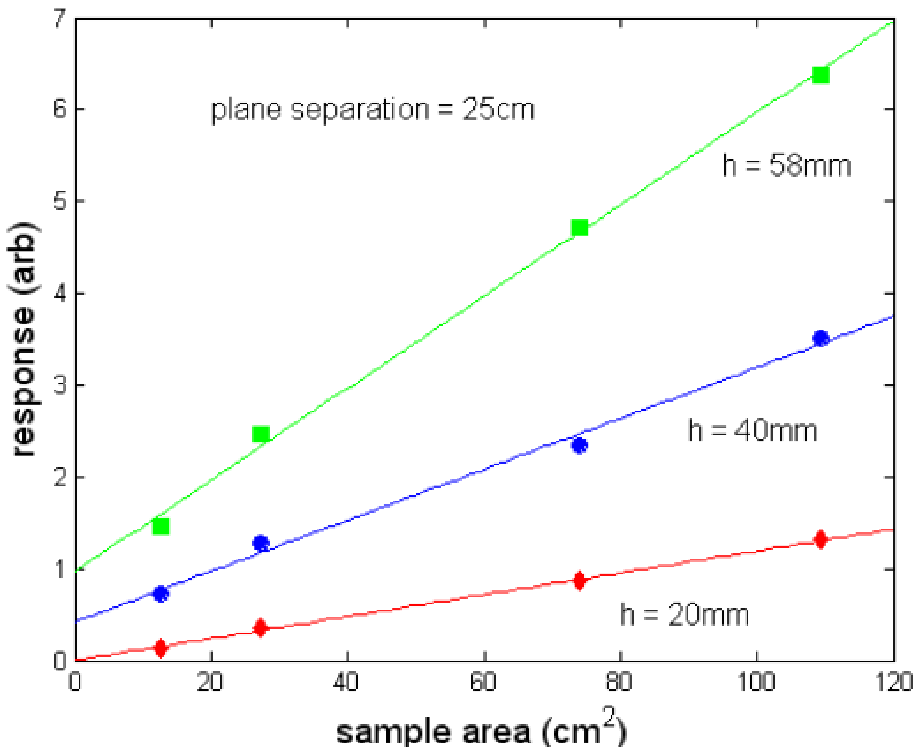


**Figure 4.** Response of CSIRO laboratory prototype CL sensor for different shapes. Sensor plane separation was 25cm. Each curve corresponds to a fixed sample height. Sample response was measured for different sample areas. Because of offsets in the response, at fixed sample area the sensor exhibits non-linearity with variable sample height.

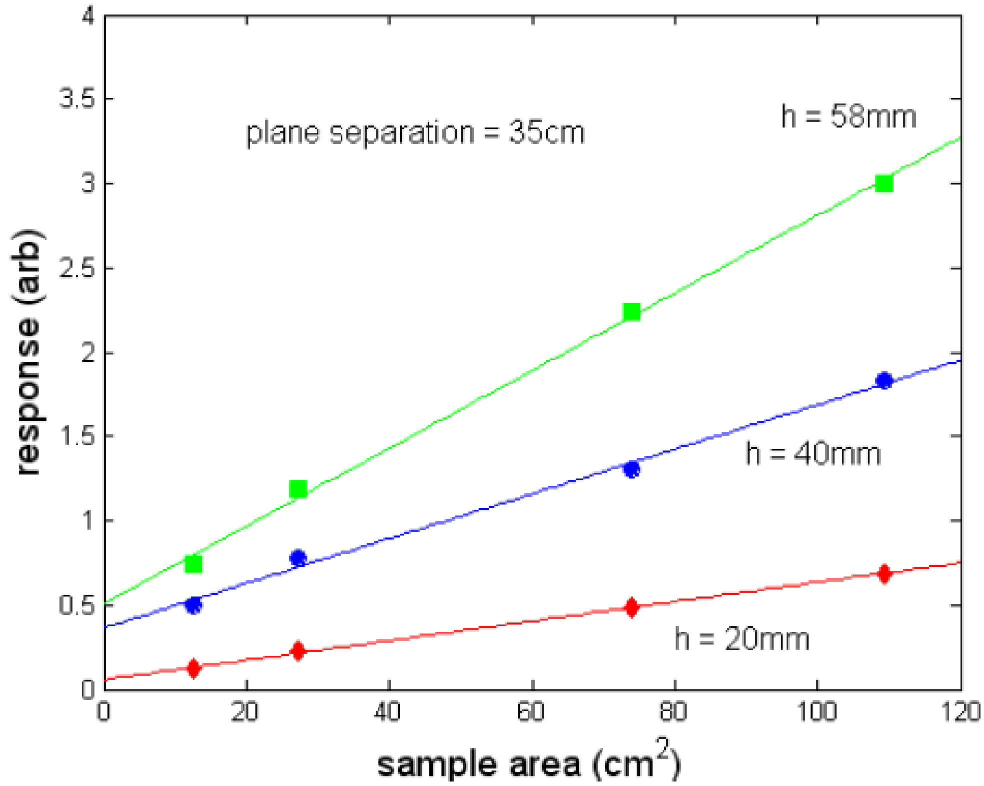


**Figure 5.** Results corresponding to conditions in Fig. 4, except sensor plane separation is at 35cm. The non-linearity is improved slightly, but sensitivity decreases.

The offsets and non-linearity in the response are believed to result from two effects:

(1) Variable proximity of the top of the sample to the upper sensing plane will cause variable electric field fringing between sample and plane. Such fringing has the effect of modifying the effective plane impedance.

(2) Fringing field associated with the charge distribution induced on the sample itself will also introduce impedance variation. That is, high aspect ratio cylinders will exhibit different fringing around the sample compared to low aspect ratio cylinders

In an attempt to mitigate effect (1) above, the separation of sensor planes was increased by 10cm to 35cm. Figure 5 shows the response in the modified sensor. Sensitivity is reduced compared to Fig. 4, and the nonlinearity is reduced slightly, but is still too large for effective trimming analysis. Separations beyond 35cm begin to loose measurement homogeneity and become undersensitive.

In another linearity test, two separate samples were inserted in the sensor simultaneously, and one combined sample, with the same mass as the two separate samples was also measured. This was repeated for several different cases. In each case the response for two separate samples was greater than the single sample. Again, this is a symptom of significant shape effect, where fringing field associated with multiple samples exceed that for a single sample. Insulating blocks and sheets were also introduced inside samples to serve as simulants for fat nodules. Often, the addition of fat simulants had only a very small effect on response (as required for a CL sensor) but cases could be constructed where additional response was found. This was particularly so for simulated nodules which were placed to introduce disjoint volumes of CL simulant.

The problems with shape variation were performed for simulants, but the general results were found to be similar for limited test samples using lean mince meat.

These results demonstrate that it is unlikely that the CSIRO sensor will be accurate enough to provide an on-line analysis of loose meat trimmings. On the other hand, it is possible that the CSIRO sensor can measure CL adequately in very controlled shape presentations, such as cartons. However, this was not the original aim of this project, and this problem seems to be adequately served by available multiple technologies.

## 4.5 Alternative electromagnetic approaches for shape compensation

In an attempt to compensate for shape effects, three other electromagnetic methods were investigated as compensators or auxiliary measurements, to negate the problems of fringing field encountered at low frequency.

(1) The basic CSIRO sensor used above was modified for use at much higher frequency ~300MHz. This result confirmed the very strong shape effects known to occur at high frequency whenever sample sizes approach quarter wavelength conditions. While such a response might prove useful for measurement or compensation if performed over a broad frequency range, it is likely to be difficult to use and implement in a straightforward manner.

(2) Attempts to measure dielectric loss in the sensor, in the hope of using this parameter for shape compensation, failed due to lack of sensitivity provided by both simulants and mince meat samples.

(3) Inductive (magnetic field based) sensors were briefly investigated as a compensation method for the CSIRO sensor. Such sensors are already in use in existing technology for detection of CL in fixed presentation like cartons. The principle of operation is to obtain correlation to CL by measuring the strength of radio frequency conduction losses in the sample. Figure 6 shows some simple magnetic loops used by CSIRO for detection of induction effects in loose meat trimmings and simulants. Uniform magnetic fluxes were applied to both simulants and trimmings. It is known that in such circumstances the response is dependant on sample area, but also that induction effects preferentially occur towards the rim of the sample rather than the centre. Response to fat simulants placed in the sample was found to be highly variable, depending on whether the fat simulant was at the centre or rim of the sample. While this limitation is probably acceptable for cartons, where overall fat distribution may be more even, the limitation is serious for measurement of meat trimmings, where fat nodules may present at very different positions. Accordingly, it was judged that induction methods based on uniform flux measurement would provide poor compensation for the case of loose trimmings. While other more complex induction sensors are capable of providing more uniform response, these are likely to have unacceptably low sensitivity and resolution.

In summary, simple methods examined for use as compensators for the CSIRO sensor in loose trimmings applications were found to provide complex responses that would probably be difficult to use or implement in an on-line system.

**Figure 6.** Simple loops used for investigation of inductive compensation of the CSIRO sensor.

# 5 Prospects for CL measurement in meat trimmings using simple electromagnetic methods

Based on the outcomes of Milestone 2, it would appear that electromagnetic methods for on-line determination of CL in loose trimmings on conveyors, employing the simple sensor designs tested, have significant difficulties. Simple electromagnetic methods suffer from shape effects, either due to depolarisation and fringing, or due to strong asymmetries in induction currents for any reasonably sized sample. The low dielectric and conduction losses in the material also contribute to difficulties. It would seem that the only hope for such methods would be the highly controlled presentation of trimmings, or a complex multifrequency or multi-technique compensation that would mitigate shape effects. Both of these approaches are at odds with the original project objectives.
However, one electromagnetic approach that would avoid these difficulties is low field NMR, where responses do not depend on the rate change of magnetic flux, but only on static and RF magnetic field strengths. Uniform fields may then be used to advantage. According to the literature, NMR has been tested on various food materials with claimed success. However, both the sensitivity and practical implementation of such a system may prove to be prohibitive.

At this point in time, alternative methods for on-line, on-conveyor measurement of CL in loose trimmings would require significant development work by CSIRO that is beyond the scope of the current project.

# 6 Recommendations

Based on the outcomes of Milestone 2, there would be little value in proceeding with planned work associated with Milestone 3. The Milestone 3 plan involves testing the sensor with multiple meat trimmings to test for correlation to CL, but CSIRO believes that the sensor will demonstrate insufficient correlation to warrant further development for this application.

CSIRO therefore recommends that Milestone 3 should not be pursued.