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Application of Imaging and Ultrasound to the Quality Grading of Beef

V.J. Anselmo
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Prepared for
U.S. Department of Agriculture
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ABSTRACT

This report presents the results of a study conducted at the Jet Propulsion Laboratory to assist the Department of Agriculture in the task of considering innovative methods for the grading of carcass beef for human consumption.

To date, grading is accomplished in a subjective manner which depends on the experience and general visual acuity of the grader. Experience can be gained with time, but even for a well-trained individual, physiological or social circumstances may involuntarily lead to errors in the discrimination of borderline grades of beef. Such errors ultimately result in economic penalties for the consumer and producer. For this reason, the development of an objective measurement technique is highly desirable.

To accomplish this study, the processing of photographic, television and ultrasound images of the longissimus dorsi muscle at the 12/13th rib cut was undertaken. The results showed that a correlation could be developed between the quality grade of the carcass as determined by a professional grader, and the fat-to-area ratio of the muscle as determined by image processing techniques. In addition, the use of ultrasound shows the potential for grading of an unsliced carcass or a live animal.

ACKNOWLEDGEMENT

The authors wish to acknowledge Dr. Richard Green, Mr. Gary Reisdorf and Mr. Richard Blackwell of the Jet Propulsion Laboratory, and Dr. Ronald Engle and Mr. Martin Swingley of the U.S. Department of Agriculture for their technical assistance and advice in the formulation and execution of this task.

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SECTION I

INTRODUCTION

A. GENERAL

Present methods of beef carcass grading are accomplished by the subjective evaluation of "graders" who are Department of Agriculture employees. Although highly trained in the performance of this task, they are nevertheless subjected to fatigue, emotional strain, and other stresses which may cause variations in the normal decision processes. Because this decision process is the primary basis for establishing the economic value of the carcass to the rancher, packer and consumer, it is desirable to formulate a methodology to produce an objective measurement from the carcass which is a function of its quality grade.

In terms of precision, the most difficult task for the grader and the most important factor in determining the quality grade, is the estimate of the percentage of marbling in the rib eye muscle at the twelfth rib. Marbling, however, also appears to be the factor most amenable to quantitative assessment by imaging or ultrasound techniques.

Image processing refers to the computer manipulation of optical, photographic or television images. To accomplish this manipulation, the image is usually digitized, i.e., each color of the image is assigned a number or set of numbers which uniquely describes that color at each position within the image. The purposes for processing images usually fall into one of two categories: image enhancement and pattern recognition. Image enhancement is the improvement in the quality of the image by removing or lessening degradations suffered by the image in its acquisition, storage or display. Pattern recognition loosely means the detection and extraction of patterns or other information from the image. As such, it covers the range of simply calculating the average value of some part of the image to isolating components of a given spatial frequency.

Areas of recent activity in pattern recognition include automatic pattern recognition to aid medical diagnosis, automatic recognition of targets, and remote sensing of environmental pollution. JPL has current investigations in all of these areas. It was because of this existing technology that the potential application of the beef grading task was undertaken.

B. EXPERIMENTS

A series of tests was conducted on samples of steaks purchased locally and brought to JPL for imaging and ultrasound analysis. The steaks were graded prior to delivery and on the day of delivery. A few changes on grade were noted. The tests which were conducted sought to determine the percent of marbling within the rib eye muscle on the twelfth rib face. Of importance in determining marbling for quality grade is not only the amount of fat present within the muscle but also the distribution of the fat within the muscle. This distribution characteristic was not considered for the preliminary tests. Problems occurred during the preliminary tests due to dehydration and discoloration of the steaks prior to testing. Nevertheless, the agreement between quality grade and area ratio as determined by the imaging methods and signal texture as determined by ultrasound was good. A definite trend, showing an increasing area ratio with increasing grade, could be seen. A similar trend indicating increasing ultrasound signal texture with increasing grade was also apparent.

SECTION II

IMAGE PROCESSING BY AREA ANALYSIS

A. METHODOLOGY

Since the amount of marbling of the rib eye steak is an important criterion in the quality grade of the steak, the question of measuring the marbling using imaging techniques was considered. This processing entails the acquisition of a black-and-white image of the rib eye steak at the 12/13th rib cut. This is the same muscle seen by the grader at the time that the carcass is graded. In this study, the image was taken by photography. The image is divided into a matrix of M x N small areas, each having a "grayness" value assigned to it. For example, white may have a grayness value of 1.0 whereas black would be 0.0. The actual range of these numbers depends on the number of gray levels to be considered in the image and the capability of the computing system being used. This array of numbers, representing the picture of the rib eye steak, is stored in a computer memory for analysis.

The methodology used for image processing by area analysis is explained with reference to Figure 2-1. A photographic camera was used to obtain black and white transparencies of the target. The transparency was digitized for storage and analysis in a computer. A histogram of the gray levels for the stored image was calculated and from it, a gray scale value was established for the discrimination between fat and lean muscle. Using this discrimination value, the image was transformed to a binary (black/white) image. The areas of fat and muscle were obtained from the binary image and the ratios of fat area to muscle area and total area were calculated. Three tests were conducted with this method.

B. TEST RESULTS

The first test utilized the photograph presented by the Department of Agriculture as an illustration of the limits for certain degrees of typical marbling referenced in the official United States Standards for Grades of Carcass Beef. This photograph is shown as Figure 2-2. The objective of this test was to separate the area of fat (white) from the area of lean muscle (gray), and to thereby determine the ratio of the area of fat to the muscle in each individual picture. It is expected that this area ratio should vary in direct proportion to the surface marbling as seen by the grader.

The steak images from Figure 2-2 were transformed to a computer image (digitized) and the areas of fat and muscle were measured. The ratios of the fat to the muscle areas were calculated and the pictures were inverted to indicate fat as black and muscle as white.

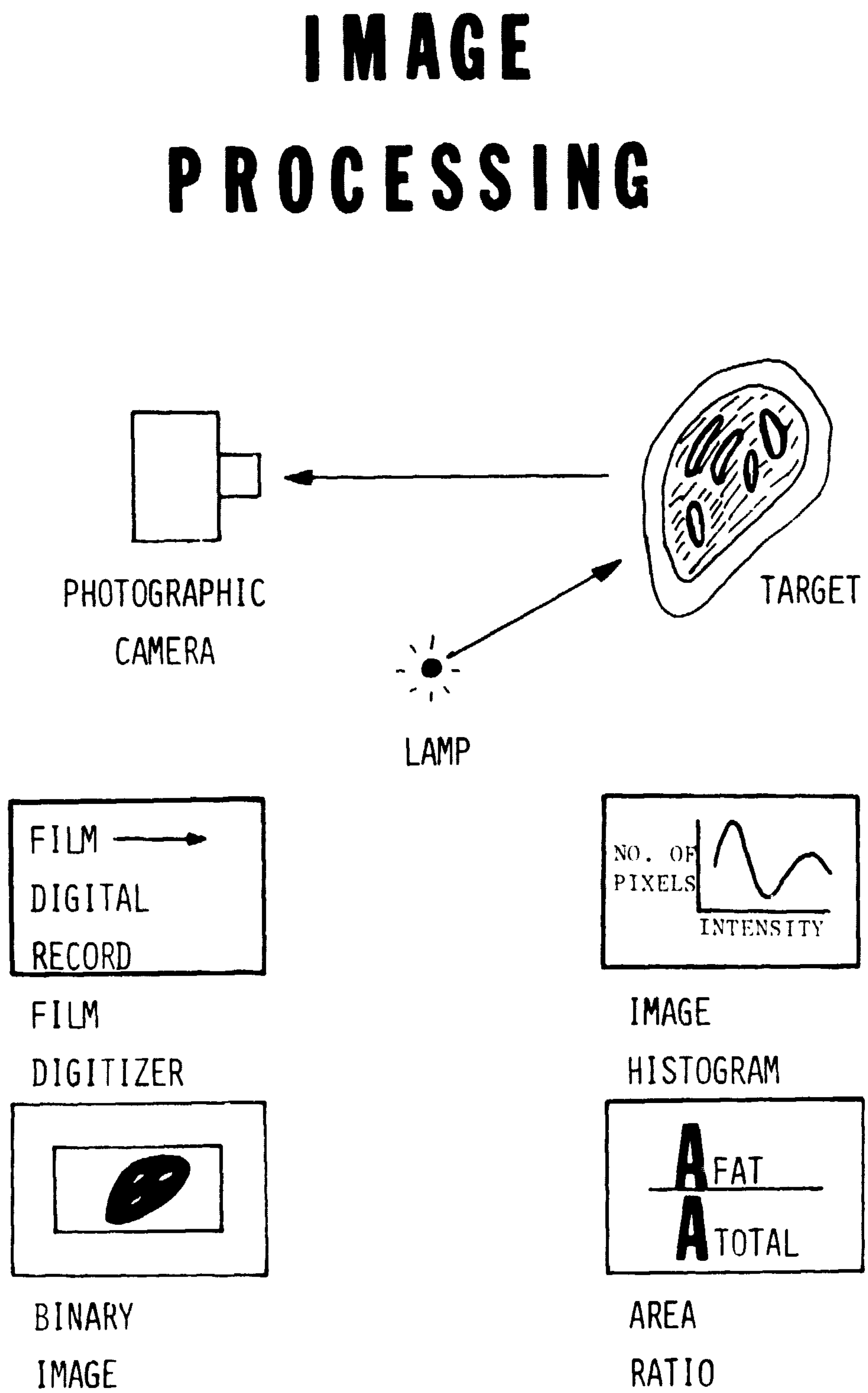

Figure 2-1. Area Ratio Image Processing

ILLUSTRATIONS OF THE LOWER LIMITS OF CERTAIN DEGREES OF TYPICAL MARBLING REFERRED TO IN THE OFFICIAL UNITED STATES STANDARDS FOR GRADES OF CARCASS BEEF

Illustrations adapted from negatives furnished by New York State College of Agriculture, Cornell University

1—Very abundant	4—Slightly abundant	7—Small
2—Abundant	5—Moderate	8—Slight
3—Moderately abundant	6—Modest	9—Traces

(Practically devoid not shown)

UNITED STATES DEPARTMENT OF AGRICULTURE
CONSUMER AND MARKETING SERVICE
LIVESTOCK DIVISION

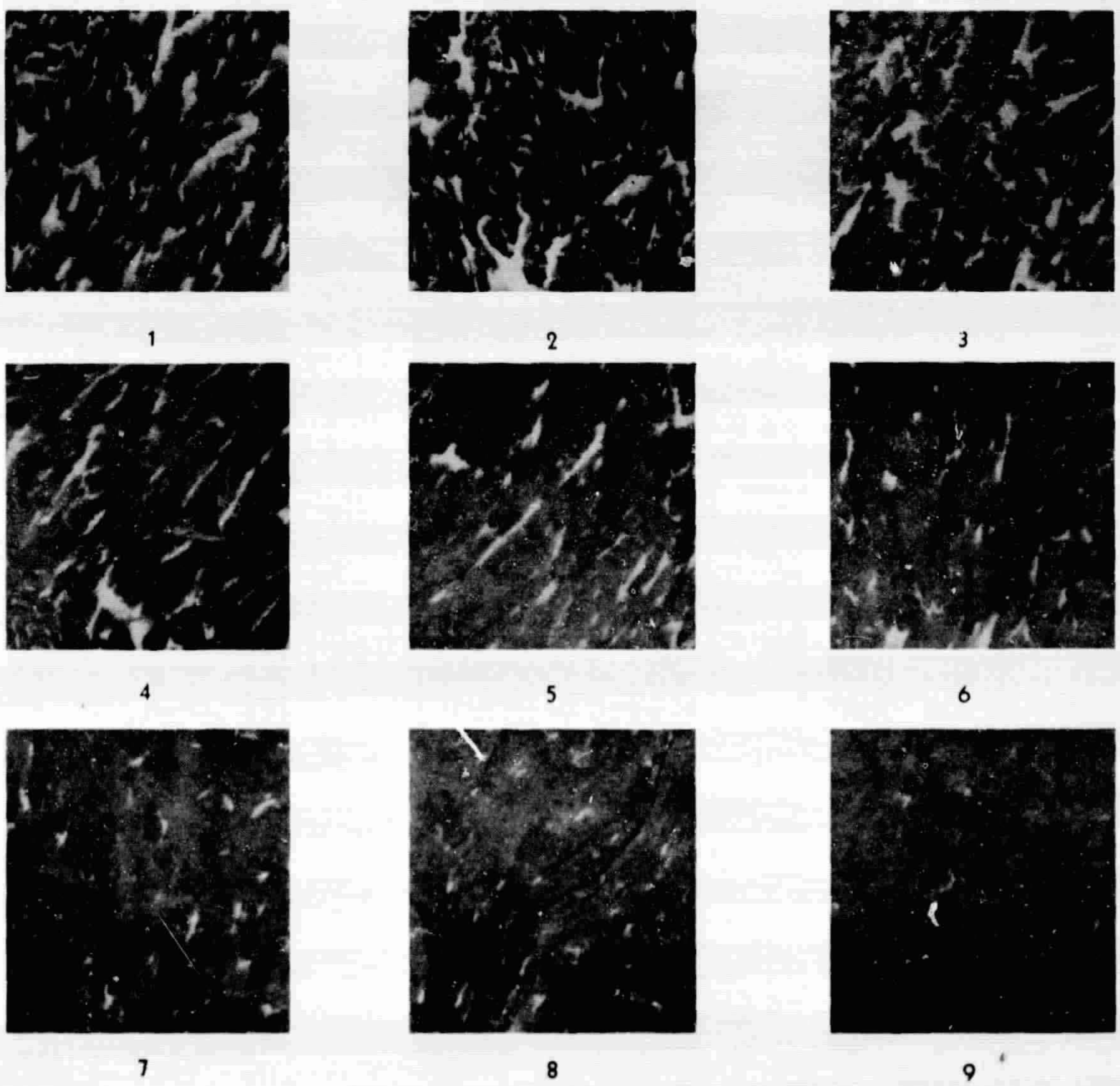

Figure 2-2. Typical Carcass Beef Grades

These pictures are shown in Figure 2-3. Each individual steak area is numbered 1, 2, 3..... to correspond to the original area of Figure 2-2. Each area is identified by the marbling description given in Figure 2-2, and the calculated ratio of area of fat to muscle is stated below the appropriate picture. With the exception of items 1, 2 and 3 of Figure 2-3, it is seen that this ratio decreases as the subjective description of the marbling indicates a reduced quantity of fat in the area of the photograph. It is apparent from discussions with personnel at the Department of Agriculture that these figures had been erroneously labeled in its original photograph and should correctly fall into the sequence shown by decreasing area ratio.

To separate the areas of fat from lean muscle, a decision had to be made as to the gray value of the respective boundaries. For example, the average value of the fat, on a scale of 0 to 1, may be 0.9 whereas that of the muscle may be 0.3. The question then arises as to what value will properly discriminate between the two. If an average value (e.g., 0.6) is taken, the optical density at the mid point between fat and lean muscle would be defined as this boundary. This approach, although apparently reasonable, must be studied in more detail. In any case, the data is presented here more as a description of the method and its feasibility than as proof of its efficiency.

The second experiment performed with this method was conducted by photographing three samples of twice-ground hamburger comprised of high (27%), medium (19%) and low (17%) fat content. These were obtained from a local butcher and the purposes of these tests were to demonstrate the area analysis method on real samples of meat and to study some of the parameters leading to the analysis. The use of hamburger was attractive for these tests because an approximate knowledge of the volumetric fat content of the target was known a priori. The measured area ratio would be expected to correlate with this known volumetric ratio. Photographs of the hamburger are shown in Figures 2-4 (high fat), 2-5 (medium fat) and 2-6 (low fat). Figures 2-4a, 2-5a, and 2-6a are reproductions of the original photographs of the hamburger with histograms of the entire image. Figures 2-4b, 2-5b, and 2-6b are sections of the hamburger taken for analysis, expanded in scale, and showing the histogram of the chosen area.

In order to place the original image of these pictures into the computer for processing, the negatives were scanned by a Perkin Elmer PDS microdensitometer, which converts the gray tones of the negative to digital numbers. This microdensitometer has the ability to look at many small areas of the negative. These small areas are called "pixels" and may be of 20, 50 or 100 microns in diameter. Part of the objective of this study was to determine the largest pixel size which could be used in the analysis. The larger the size, the less computer time it would take to perform the analysis. The pictures shown in Figures 2-4a, 2-5a, and 2-6a were made from the 20 micron pixel size.

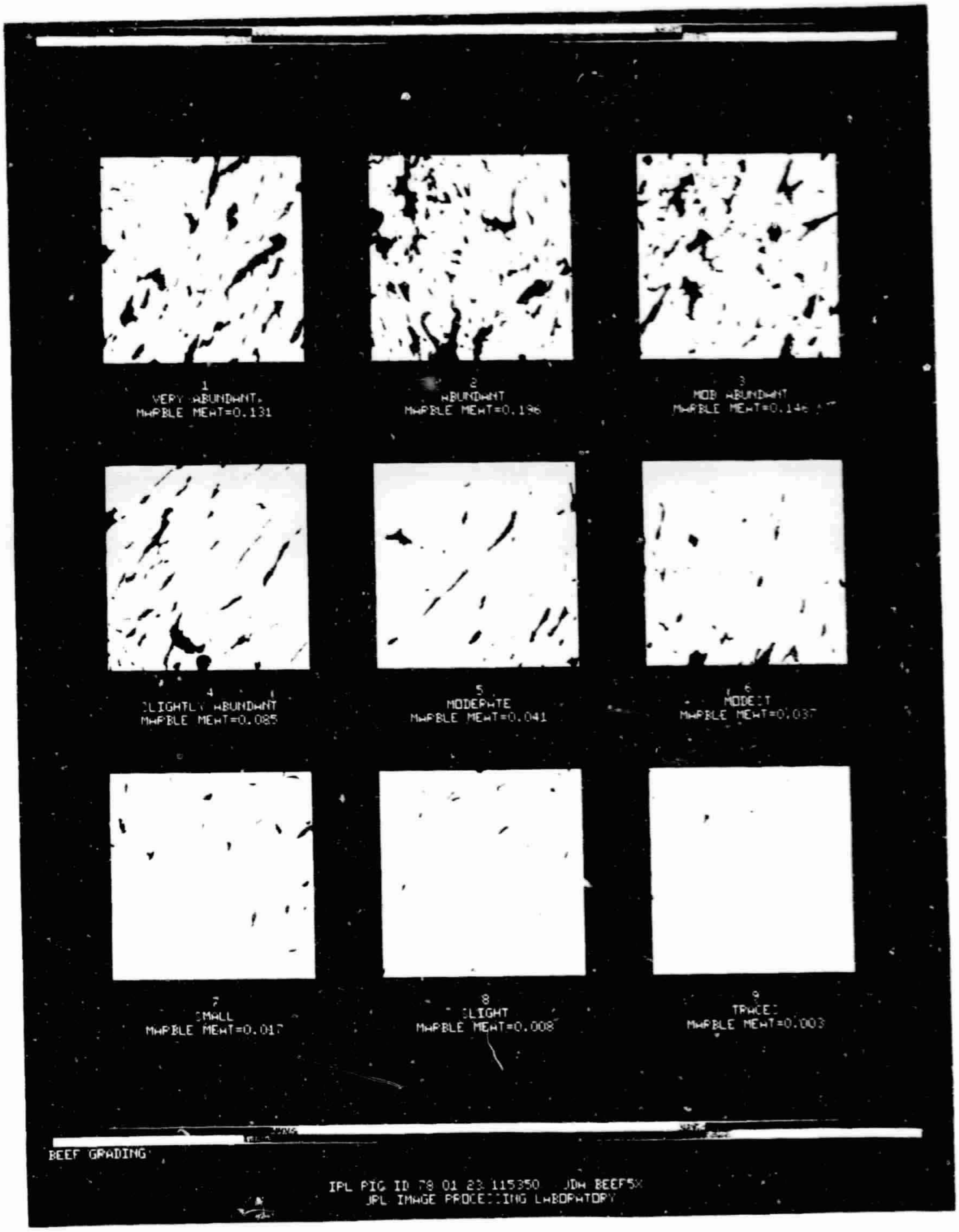

Figure 2-3. Area Ratio Image Processing of Typical Carcass Beef Grades

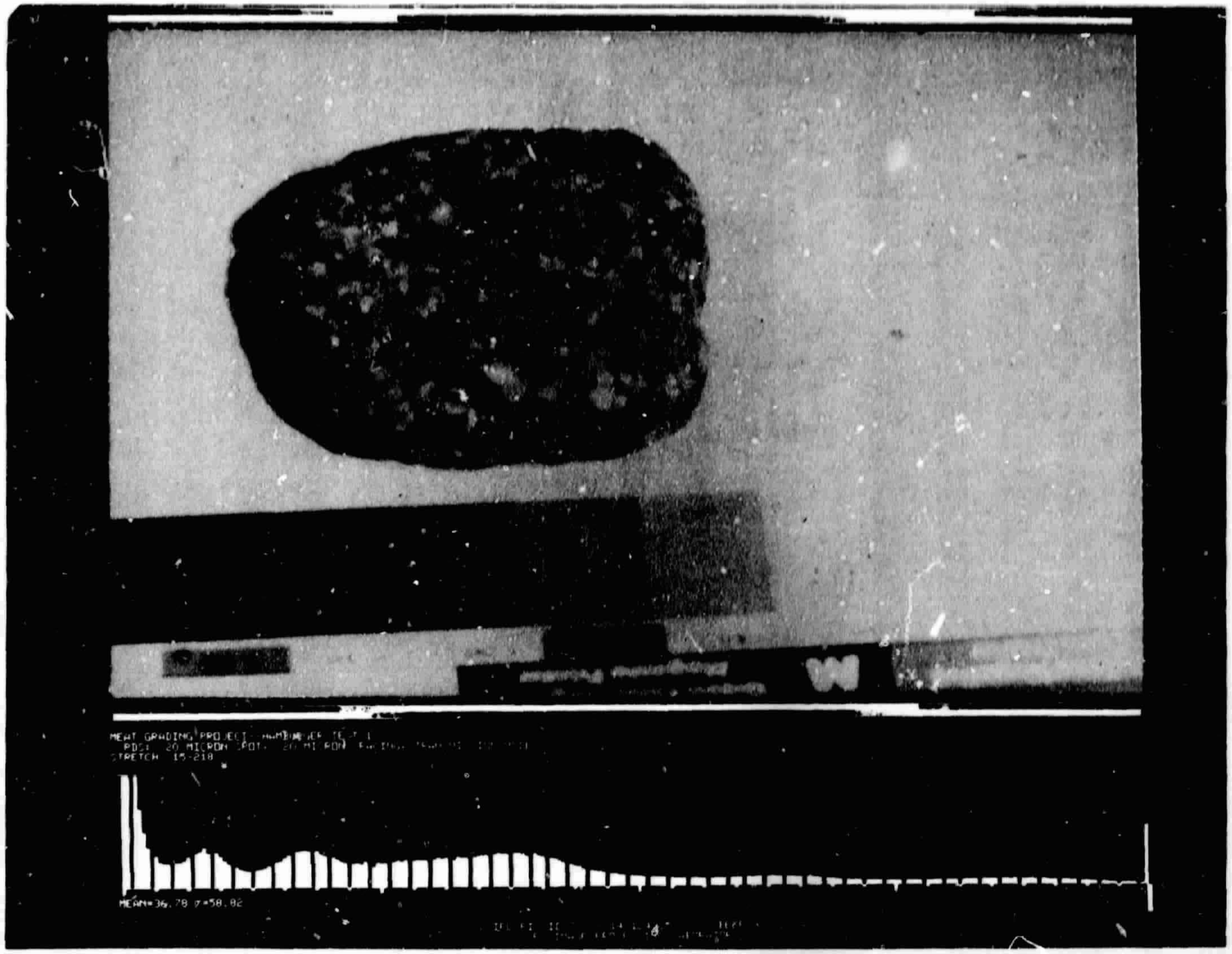

Figure 2-4a. High Fat Content Hamburger

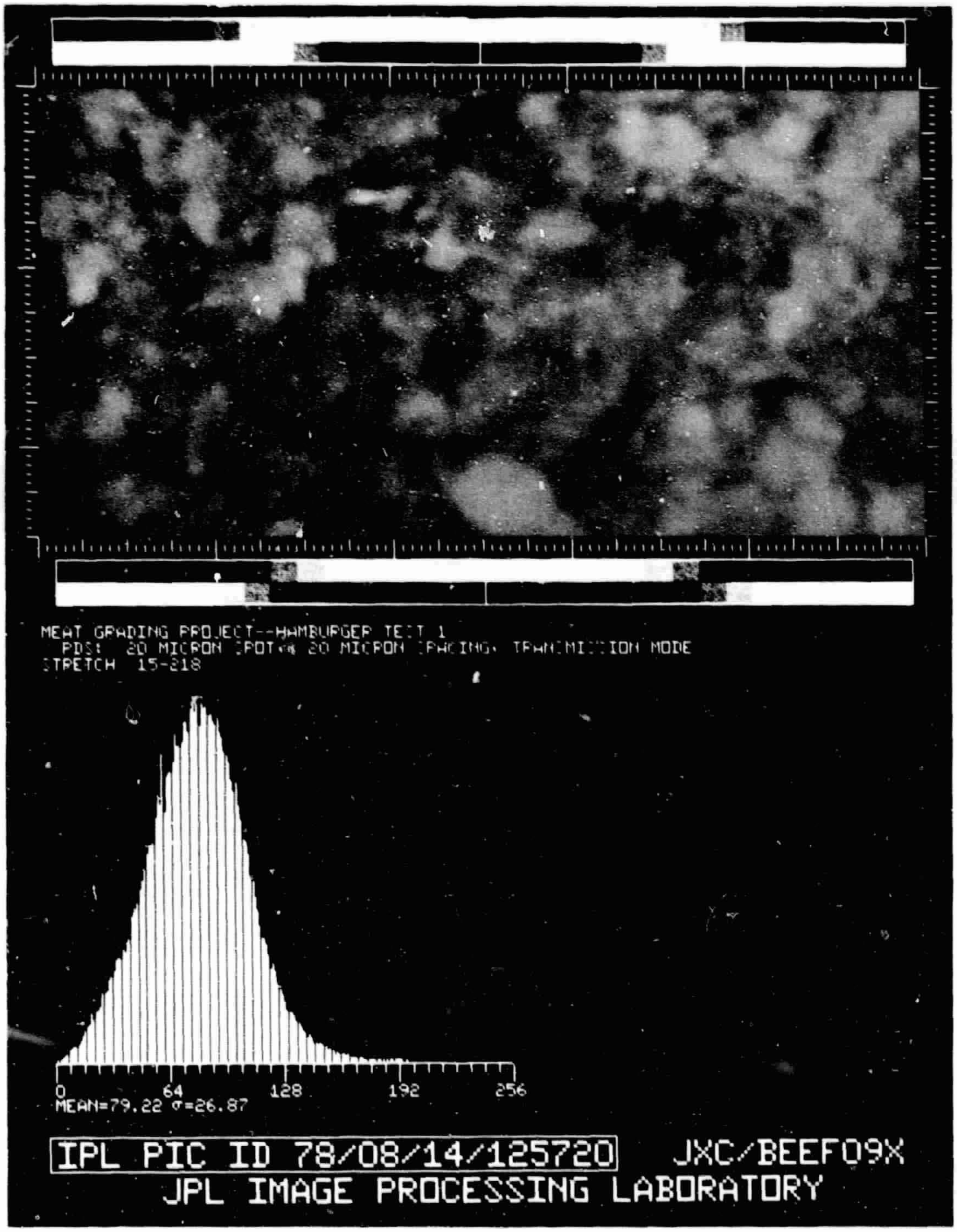

Figure 2-4b. Isolated Section of High Fat Hamburger

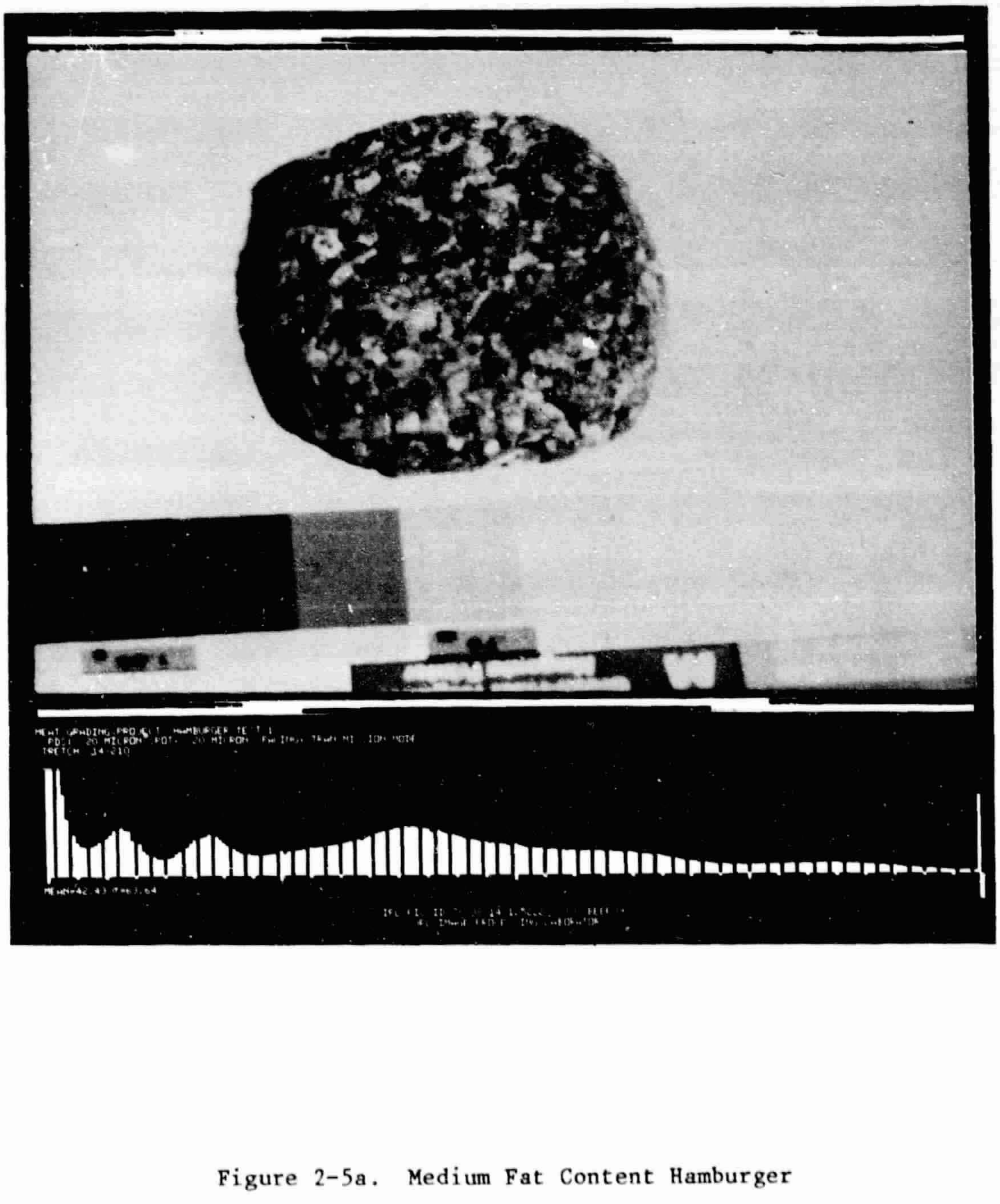

Figure 2-5a. Medium Fat Content Hamburger

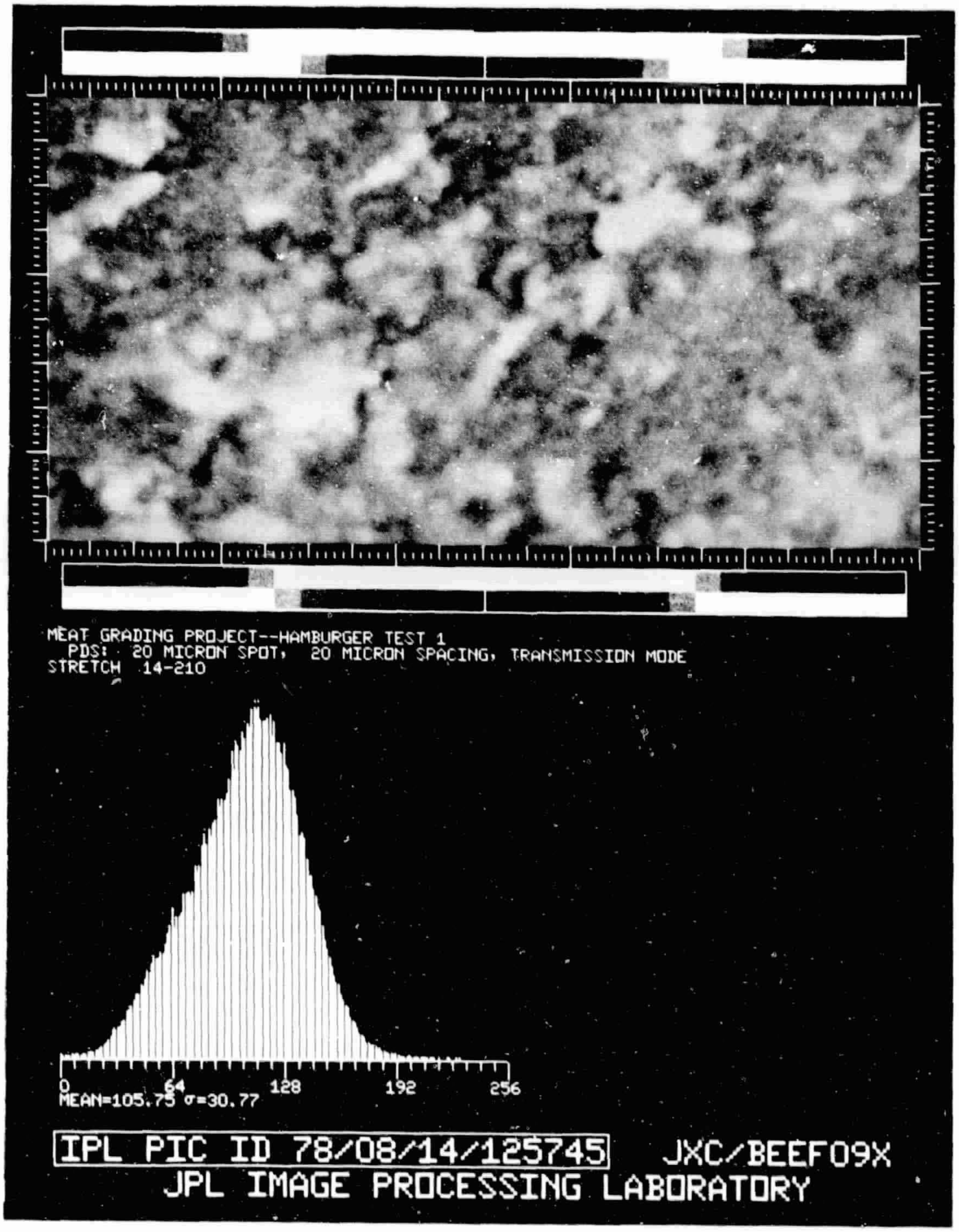

Figure 2-5b. Isolated Section of Medium Fat Hamburger

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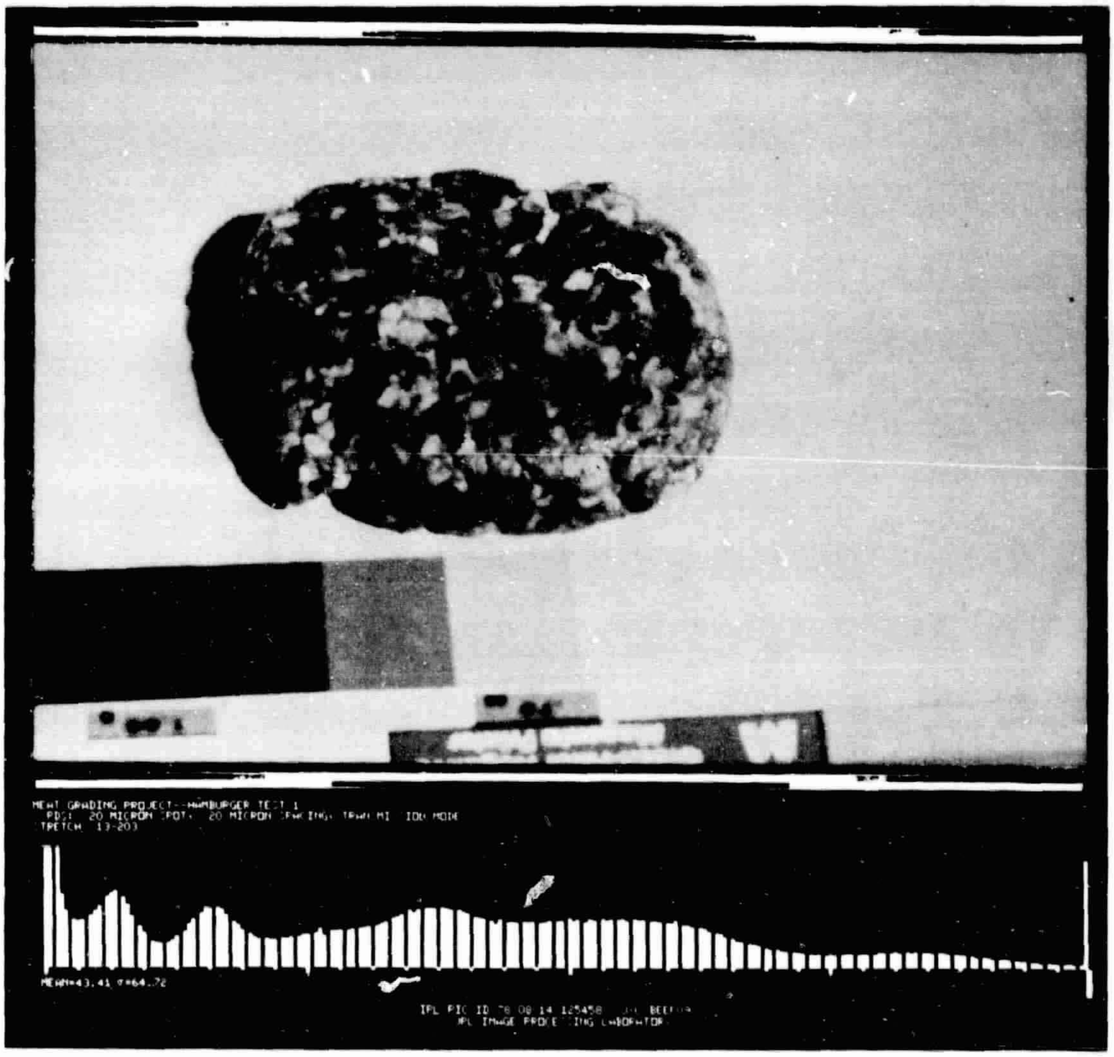


Figure 2-6a. Low Fat Content Hamburger

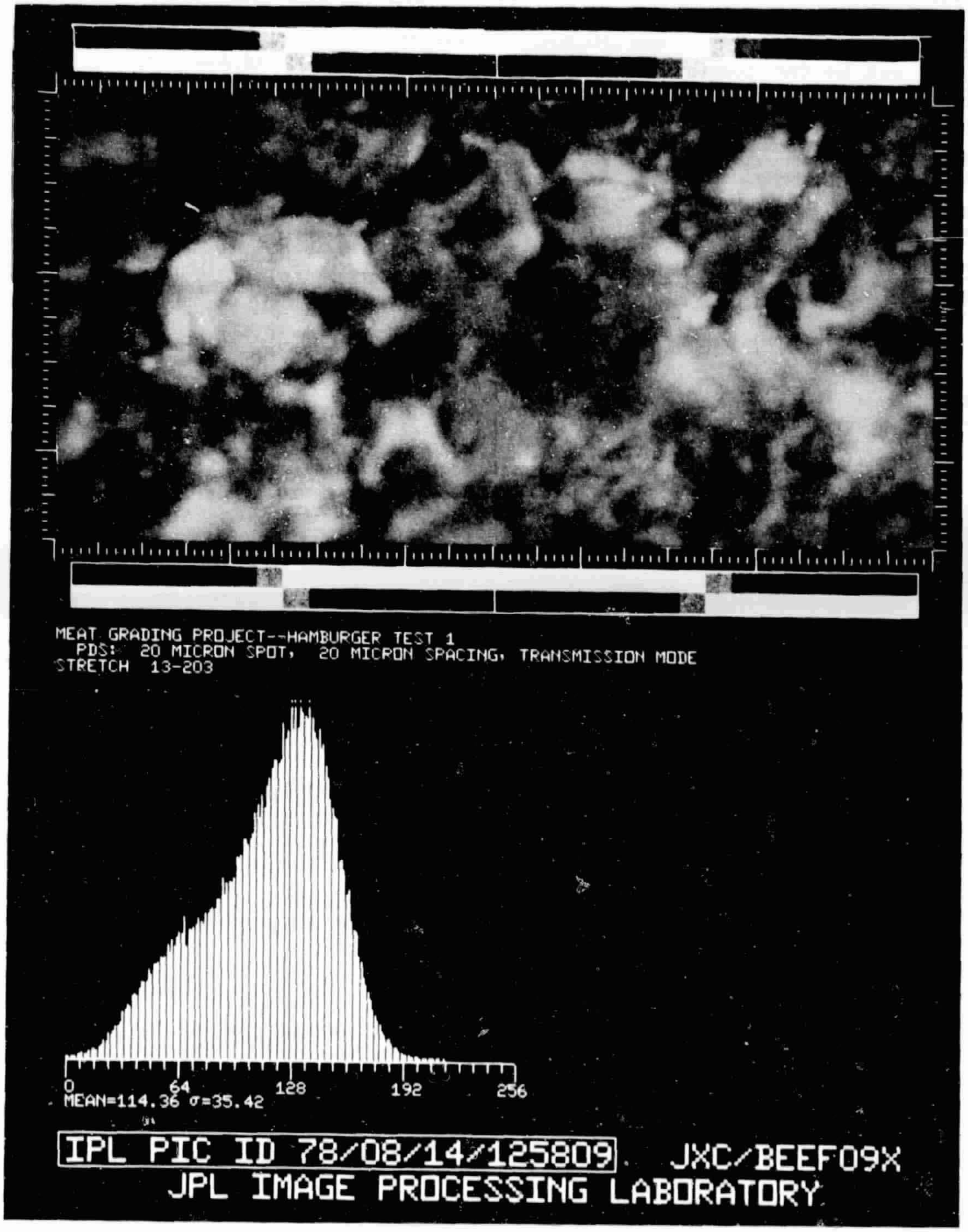


Figure 2-6b. Isolated Section of Low Fat Hamburger

These images of high, medium and low fat content were also obtained with 100 micron and 50 micron resolutions and stored on tape for access by the computer for processing. The resulting images, i.e., the photographs transformed to digital matrices, were processed so that three types of data were produced: (1) histograms representing the frequency at which various numerical values of "grayness" occurred on each picture, (2) contrast-enhanced photographic images of the original photographs and (3) point-by-point computer printout listings of the numerical values of the image for selected portions of the image. These point-by-point listings were also accompanied by histograms of the selected areas.

From these data it was possible to determine a rationale by which areas of lean muscle and fat could be separated for each category of hamburger and for each pixel size. The results of this analysis are shown in Table 2-1.

Approximate values of fat content for each sample of hamburger are given in each column and labeled as high, medium or low. When scanned at a 20 micron pixel size the data representing the area ratio of fat to total area were .3970 (39.7%), .2188 (21.8%) and .1860 (19.6%) for each sample. Although the results do not agree well with the high fat content sample, fair agreement exists with the medium and low fat samples. Total agreement, however, was not the primary goal of the test, although it is the most compelling to consider. The more important result is the ability of the analysis to differentiate between high, medium and low fat content in a relative manner. This occurs with the 20 micron scan but not the 50 or 100 micron scans where the area ratios of the medium and low fat samples appear to lose their relative accuracy. This error could result from a lack of sufficient resolution at the larger pixel sizes, from an erroneous choice of muscle/fat interface or from a real variation in fat content of the surface considered. The results, however, show that a relative differentiation in surface fat can be made using the area analysis method from a photographic image if image scans are made at 20 microns.

The third test utilized steaks graded by a Department of Agriculture grader and analyzed in the same manner as the hamburger. In total, 17 steaks were chosen for area analysis in four grades: prime, choice, good and standard. A typical photograph of a steak is shown in Figure 2-7. This is a reproduction by the computer of the original photograph showing the steak, the reference gray scale and an outline of the area of muscle chosen for analysis. Figure 2-8 shows the isolated area with its histogram. It is this area which is considered when the area ratio of fat to total area is calculated. The threshold value determined from the histogram separates the histogram into fat and muscle areas. From these values the ratio of fat to total area is determined.

Table 2-1. Hamburger Test Results

Meat Grading Project

Test 1

Relative Fat Content (Hamburger)	High	Medium	Low
Approximate Fat Content (Volumetric)	.27 ± .03	.19 ± .03	.17 ± .03
Area Ratio at 20 Micron Scan	.3970	.2188	.1860
Area Ratio at 50 Micron Scan	.3319	.1813	.1848
Area Ratio at 100 Micron Scan	.2932	.1480	.1460

This procedure was followed on a number of steaks chosen as representative of each grade. A number of steaks presenting special problems were also considered for analysis. The results are shown in Table 2-2. Each steak is identified by number, e.g., 2, 6, 34, etc. The grade assigned to the steak and the percentage of marbling calculated for each steak is shown adjacent to the respective steak.

Since the steaks were not delivered individually wrapped, a number of them became discolored, acquiring a brown appearance on the face to be used for analysis. Consequently an area analysis was conducted on the opposite side of the steak (15th rib) as well as on the side to be graded (13th rib). These 15th rib images were noted with an asterisk and are shown as 6*, 22* and 34*. With the exception of 6* which has a large amount of specular reflections (glare) as compared to 6, the 15th rib surfaces show considerably less marbling than the 13th rib surface. This is consistent with the a priori knowledge of decreasing marbling in the posterior sections of the muscle, e.g., see 22-22*, 34-34*.

Other distortions in the trend of Table 2-2, showing increasing marbling with increasing quality grade are due to the presence of specular reflections from the steak surface. Because these reflections appear "bright" on the photograph, the computer identifies them as fat and includes their area into that calculated for fat. This produces an erroneously high value for the percent

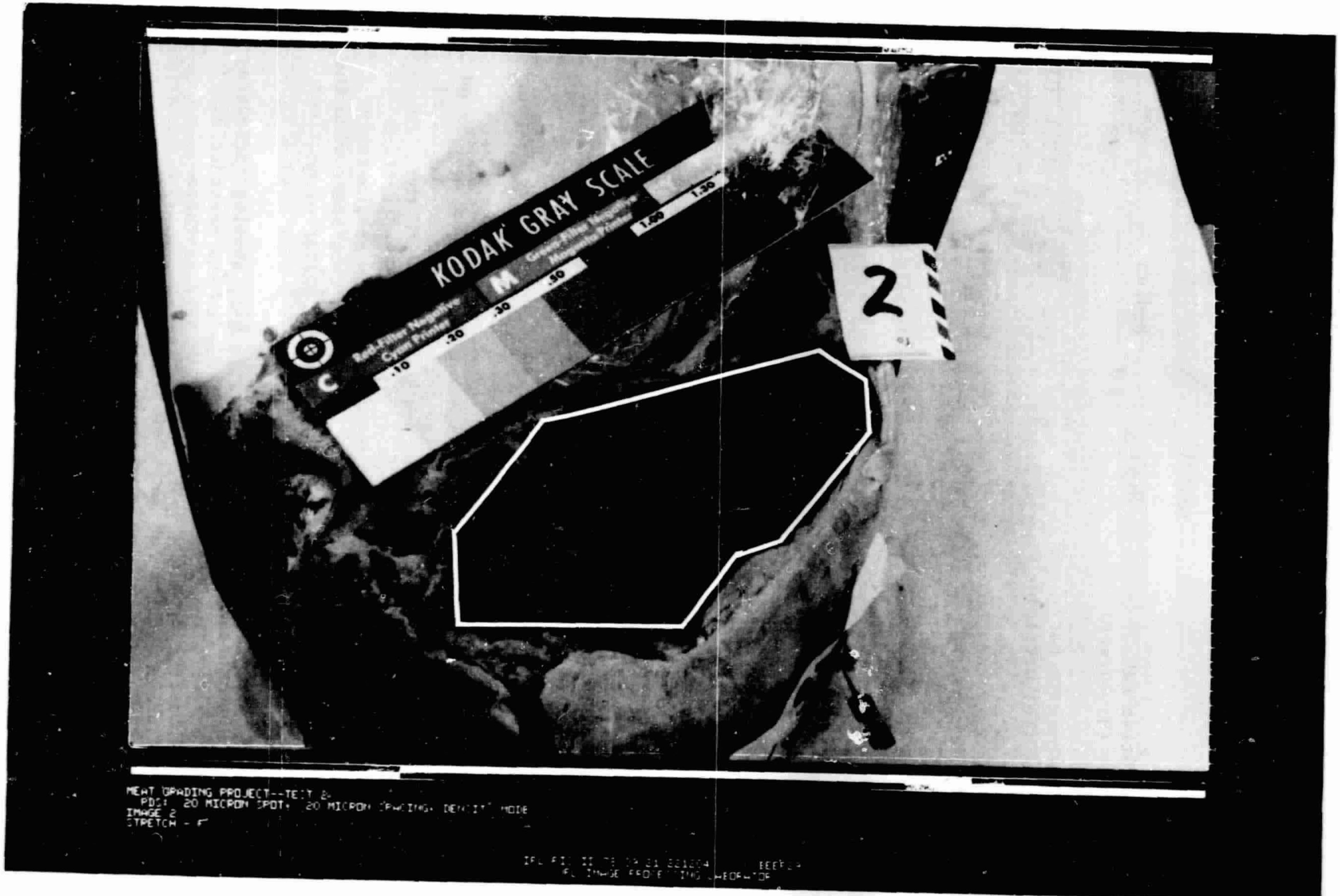


Figure 2-7. Typical Steak Photograph

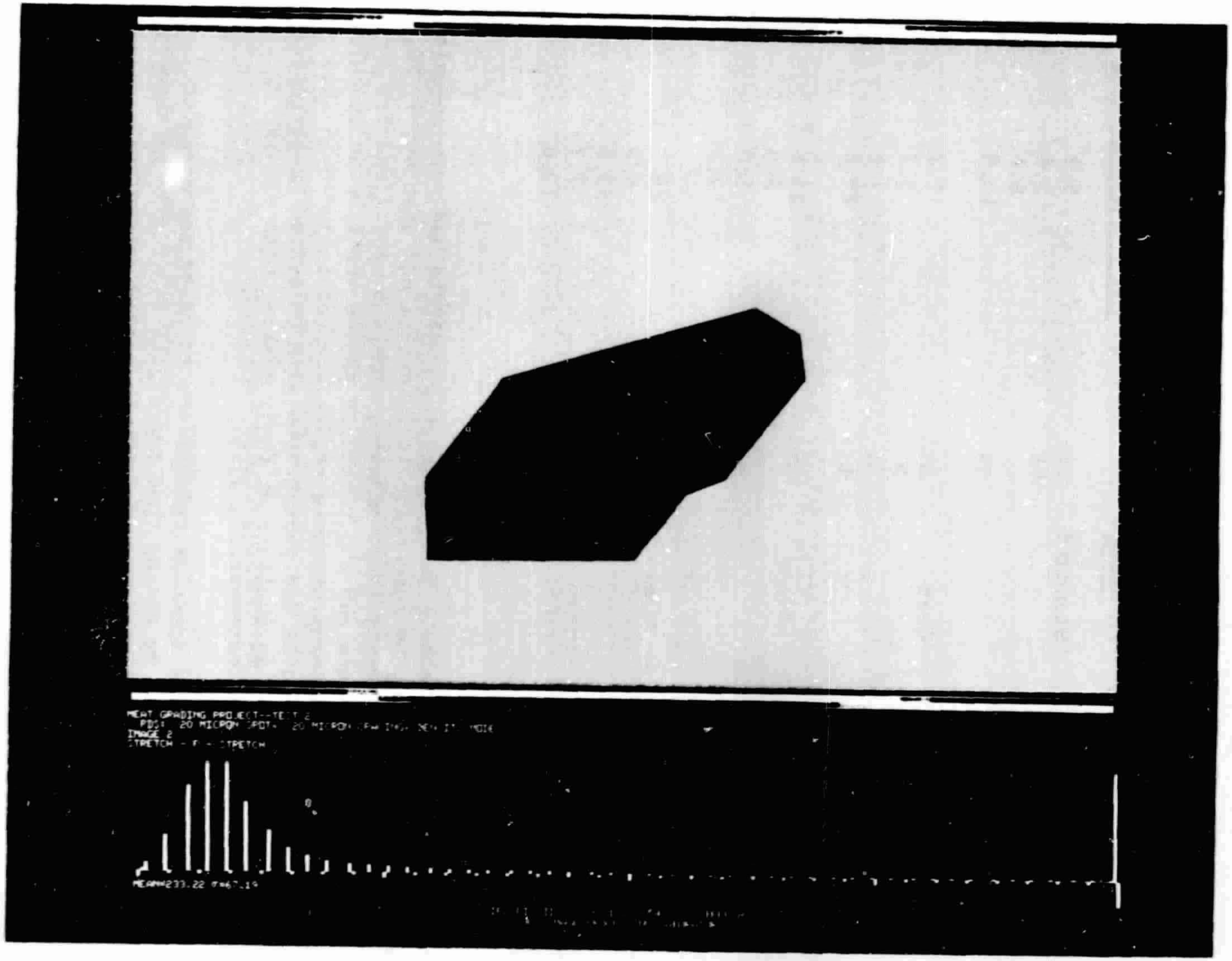


Figure 2-8. Isolated Section of Steak for Analysis

Table 2-2. Steak Area Analysis Results

Meat Grading Project

Test 2

Image	Grade		Percentage Marbling
2	Standard	TR-	6.9
6		TR	5.6
6*			6.8
7		TR	14.0
11	Good	SL	1.7
15		SL	5.7
19		SL	7.6
20		SL+	26.8
22	Choice	SM-	24.3
22*			8.0
23		SM+	8.0
24		SM-	22.4
34	Prime	SL AB	20.0
34*			9.9
35		AB+	43.8
37		AB+	51.7
40		MO AB	19.8

marbling of those steaks. Nearly all of the steaks had some specular reflections; however, by inspection it is determined that 6*, 7, 20, 22, and 24 had relatively large amounts, steaks 6, 19, 2 and 23 showed moderate amounts and the remaining showed small or no specular reflections. Photographs of these steaks are not included in this report. These test data and photographs were presented to personnel of the Department of Agriculture at their meeting with JPL in Washington, D.C. on September 29, 1978.

The tendency of specular reflections to raise the measured marbling can be seen by noting that the steaks showing large amounts of reflections as given above also show increased percentage calculated marbling as given in Table 2-2. This is true for 7 in the standard grade, 20 in the good grade, and 22 and 24 in the choice grade.

Reflections from the steaks therefore are a source of error to the image processing methods, if not removed physically or mathematically from the picture. Physical removal may be possible with the use of polarizing filters. The reflected light will be polarized because the steak is a non-metallic surface. Proper use of the polarized filters should eliminate or greatly reduce this problem.

The importance of image processing by area analysis is the ability to determine a general correlation between percentage marbling as measured from photographs and the quality grade as determined by the grader. This is shown most clearly in Figure 2-3 by the decreasing values of fat to muscle, (marble/meat) indicated with decreasing quality grade. The results of the tests with hamburger, Table 2-1, also indicate a good correlation between the percentage of fat measured on a specific area of the hamburger surface and the approximate fat content as determined by pyrolysis. The steak tests results in Table 2-2 are less attractive until one analyzes them on an individual basis. The ability to see reduced marbling in the posterior section of the muscle is an important element suppporting the methodology. Also, the trend indicating increased marbling with grade can be realized if one considers the deleterious effect of reflections on the calculation of marbling.

SECTION III

IMAGE PROCESSING BY MULTISPECTRAL ANALYSIS

A. METHODOLOGY

It is recognized that apparent fat content of the muscle is not the only valuable criterion in evaluating the quality grade of the carcass. Also of importance are the non-visible fat and the color of the muscle and the fat. These characteristics were studied by the multispectral imaging technique described in Figure 3-1. A device called the spectrometer receiver is a television system capable of receiving simultaneous images in up to 3 channels. Each channel represents an image filtered in a specified wavelength range. The diagram at the bottom of the figure shows the incoming image being divided by a beam splitter and assigned to a spectral channel. Silicon reticon devices capture the filtered image and send their electrical signal to an image storage device where the digitized image is held for processing. The image processor accomplishes the necessary manipulations of the numerically-coded filtered images and the resulting analysis is displayed as a pseudocolor image. The system replicates the general methodology used for electromagnetic energy analyses (e.g., UV, visible, infrared, etc.) of samples, but accomplishes this analysis with an image rather than the integrated signal from a small area of the sample. This allows the availability of the spatial distribution of the spectral characteristics of the target. Consequently the technique of multispectral imaging could also be called imaging spectroscopy. Two tests were conducted using this technique.

B. TEST RESULTS

A system as described in Figure 3-1 and which is presently being used for medical diagnosis, was used to study four rib eye steaks. These steaks were classified by a senior Department of Agriculture grader. Analysis of the steaks was accomplished within 4 hours of grading. The multispectral characteristics of the four grades of steaks shown in Table 2-2 were calculated from images obtained in the yellow-green (5450 Å), red (6300 Å), and very near infrared (8000 Å). The images were improved by (1) a linear stretch contrast enhancement which placed the full dynamic range within the gray scale of the muscle areas, (2) the formation of the ratio of the infrared/red, infrared/green, and red/green images, (3) the final contrast enhancement of the ratioed images and (4) the production of the pseudocolor image by assignment of the infrared/red image to the red channel of an RGB color monitor, the infrared/green image to the green channel, and the red/green image to the blue channel. This resulted in the photographs of steaks shown in Figures 3-2a, 3-3a, and 3-4a. Note that as the quantity of marbling decreases from the prime to the good grades, the amount of "bright" area in the muscle also decreases. This implies that the spectral analysis is

MULTISPECTRAL IMAGING

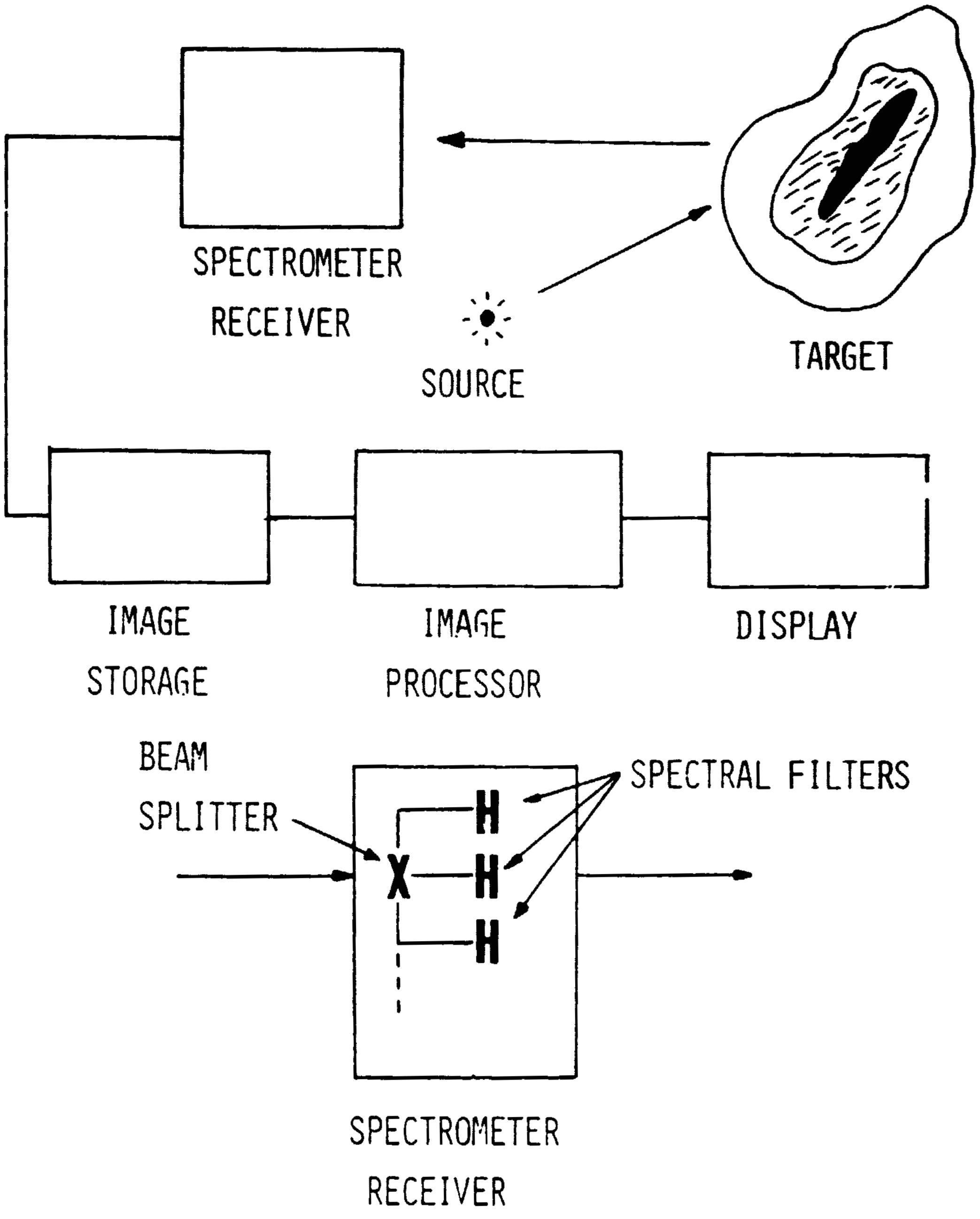
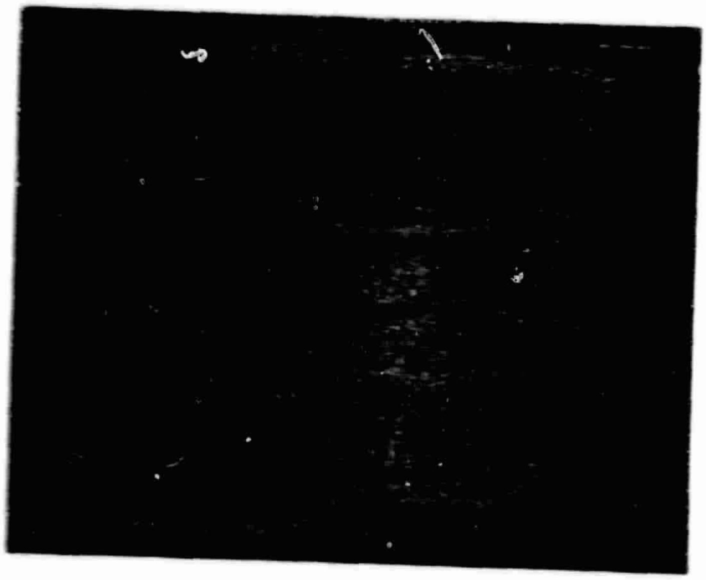


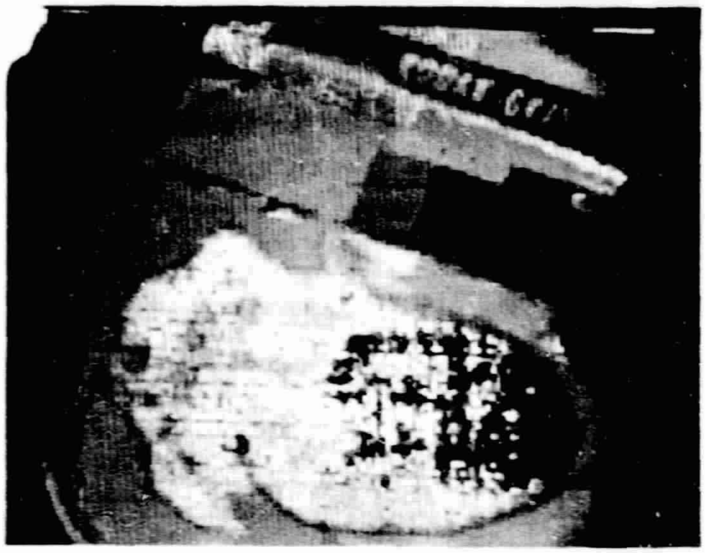
Figure 3-1. Multispectral Imaging Analysis

(a) Multispectral Analysis

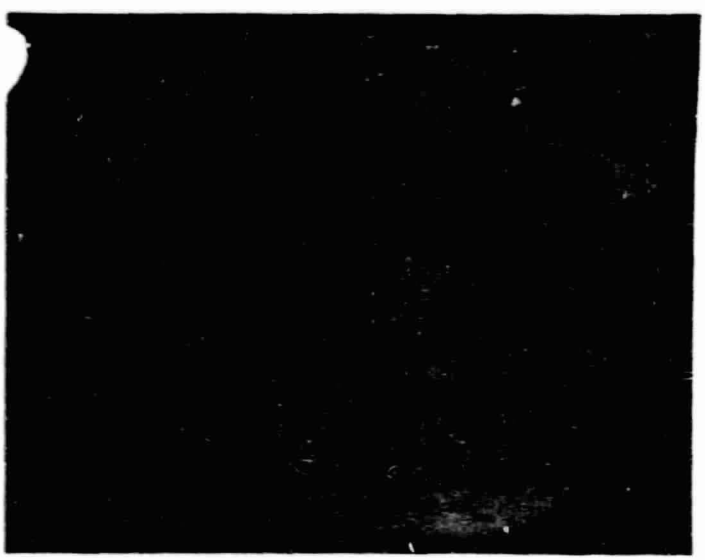


(b) Binary Image

Figure 3-2. Prime Grade Steak

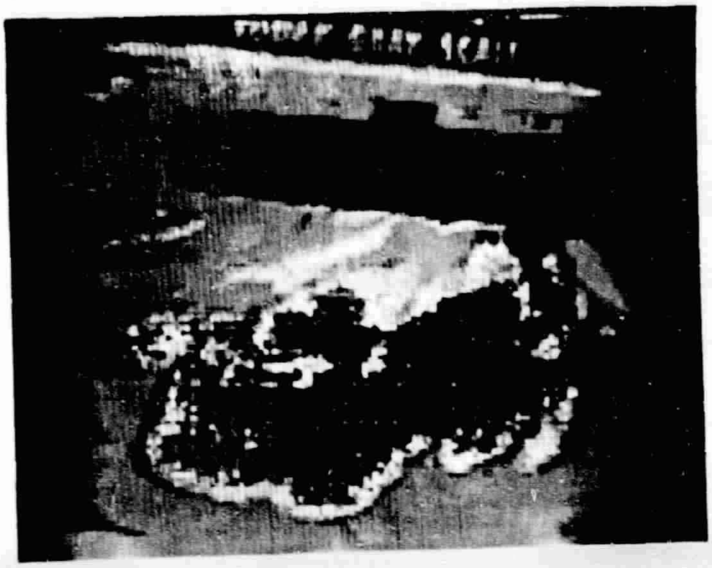


(a) Multispectral Analysis

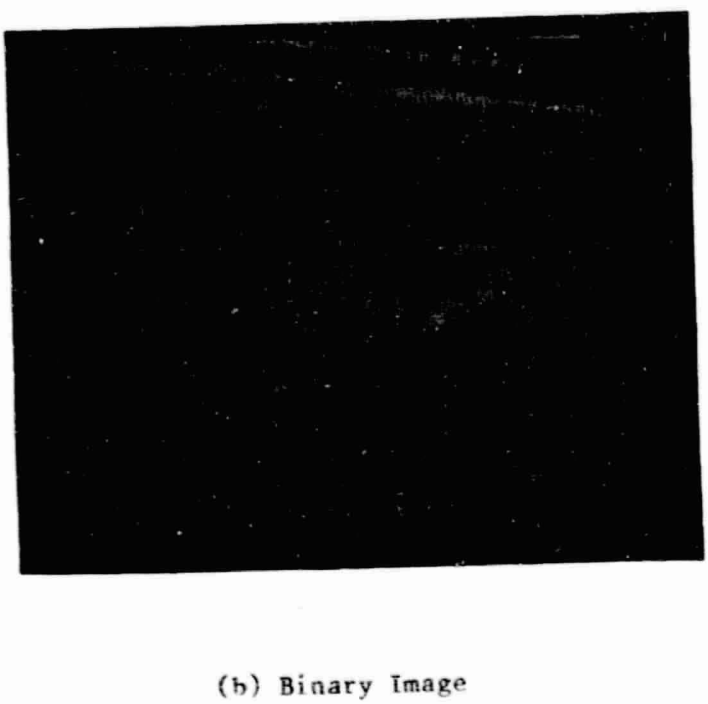


(b) Binary Image

Figure 3-3. Choice Grade Steak



(a) Multispectral Analysis



(b) Binary Image

Figure 3-4. Good Grade Steak

classifying fat content by image brightness. Also note that each of the steaks indicate a non-uniform distribution of bright area which decreases from the external to the internal muscle. This distribution is consistent with the distribution of fat as it originates from the main vessels in the muscle which tend to concentrate in the external section.

Figures 3-2b, 3-3b and 3-4b depict a second method of noting this apparent distribution of fat. A binary image is formed in which areas containing a high degree of intramuscular fat are bright, whereas those with lower amounts are black. By using a technique such as this and with the additional information of the area of the muscle, the percentage of the muscle with a large concentration of intramuscular fat could be determined. This is done by counting the bright pixels and dividing by the total number of pixels within the boundaries of the muscle. These data, although intuitively reasonable, were not substantiated by a quantitative measurement of the distribution of intramuscular fat. Fat content at the surface should be a planned measurement in future testing due to the non-uniform distribution over the muscle area.

In the second multispectral test, 40 steaks were obtained, 10 each of prime, choice, good and standard grade as determined by a Department of Agriculture grader. The objective of these tests was to duplicate the results of the first series and improve the demonstration of the feasibility of the multispectral analysis. Logistics problems, however, prevented the data from being taken until 4 days after grading and storage in a refrigerator. At this time visible changes in the color of the muscle and from dehydration were noted. The multispectral tests were conducted as in the first test, however the resulting data showed a wide dispersion of characteristics which did not correlate with fat content implied by grade. It is apparent that this analysis must be conducted on fresh steaks.

SECTION IV

ULTRASOUND ANALYSIS

A. METHODOLOGY

Ultrasound has become an established technique for imaging and measuring tissue interfaces in medicine and in some areas of agriculture. In agriculture, ultrasound has been routinely used for measurement of the backfat thickness of hogs for well over a decade and has recently been adopted for pregnancy testing of sows. In medicine, ultrasound is currently the fastest growing specialty. Being non-invasive, it is particularly suitable for use in obstetrics. The ability of ultrasound to demonstrate motion and flow provides a unique tool to the cardiologist. In these fields and in others, such as internal medicine, ultrasound provides an image determined by the mechanical properties of the tissue, which complements the information of x-rays and CAT-scanners whose images are based on the atomic number density of the tissue.

The medical ultrasound instruments are basically a version of the military sonar which is scaled down in both power and in wavelength. This is described in Figure 4-1. The system emits a brief burst of ultrasound energy, typically of 2.25 MHz in frequency, 20 milliwatts in power and around 1 microsecond duration. A 14° beam angle was used for this experiment. As this sound wave propagates through the fluids and soft tissues of the body, approximately 0.01% to 1% of the energy is reflected back toward the transducer at each interface, the exact amount depending on the particular interface involved. If the interface is approximately perpendicular to the transducer, a particularly strong echo (specular reflection) is received and the distance of the interface from the transducer can be measured with an A-scan instrument. The captured signal is amplified and processed for display.

B-scan instruments utilize the information of the A-scan, together with the position and orientation of the transducer, to construct a two-dimensional image. The simplest of the B-scan instruments display only the presence or absence of an echo above a predetermined threshold. They depend on scanning the organs from a variety of angles so their outlines can be built up on the display screen by specular reflection.

The grey-scale B-scan instruments display not only the strong specular echoes but the finer echoes from within the organs as well. These fine echoes are from interfaces that are not large compared to the wavelength of ultrasound (0.68 mm at 2.25 MHz) and consequently are not directional in their scattering properties. Although the echoes from these fine structures are much weaker than the specular echoes from large, regular boundaries, they are imaged equally well regardless of the direction from which they are viewed by the transducer. Different organs and different pathological states of an

ULTRASOUND

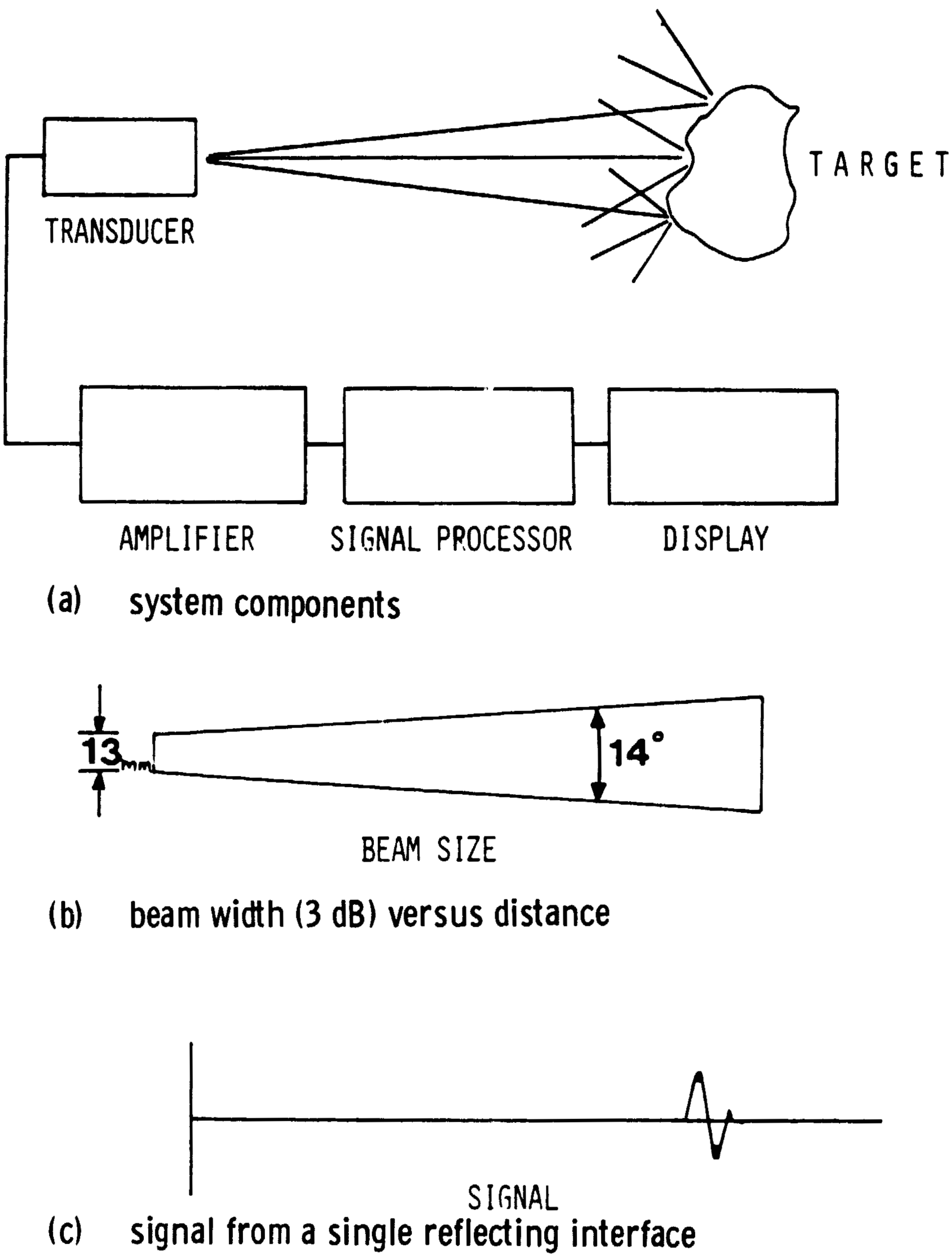


Figure 4-1. Ultrasound Methodology

organ produce different textures in the image. Since a textural image is produced, the organs can be located without scanning from many directions to produce the complete outline by specular reflection.

This type of ultrasonic tissue identification should be applicable to the identification of the various grades of beef. Ultrasound is particularly suitable since the grade is determined by the texture of marbling and a fat-muscle interface is a very strong ultrasonic reflector. A system could use a conventional B-scan display which provides a picture for subjective judgment, as with medical ultrasound. Better objectivity would be provided, however, by electronically analyzing the received signal for the desired texture and providing a numerical readout for quality grading which is free of human judgment. Since the ultrasound signal is directly related to the marbling that is observed by the grader in a hanging carcass, an excellent correlation would be expected.

Yield grading could also be done from an ultrasonic image since the thickness of the fat under the skin and within the carcass could be quantified at various points on the carcass.

B. TEST RESULTS

Preliminary experiments were conducted to determine whether the ultrasonic signatures of the beef would correlate with the quality grade. Since this is to be a feasibility test, no attempt has been made to optimize all possible system operating parameters, such as frequency, angle between the muscle fibers and the sound beam, gain, the detection and display scheme, etc. A simple set of conditions was chosen, with the objective of displaying the resulting A-scans as a subjective indication of the correlation between ultrasonic echo patterns and the conventional grading. If an effect can be observed, it can be quantified by suitable instrumentation.

This study used the same 40 beef specimens that were used for the multispectral imaging and for the image processing. These had been graded by a USDA supervisor, with 10 samples being chosen out of each of the following USDA grades: Prime, Choice, Good and Standard. Although these tests were conducted three days after the imaging studies, the results with fresher meat would, if anything, be expected to be better in their correlation.

The equipment consisted of a 2.25 MHz unfocused transducer, of 0.5" diameter and moderate damping. A wideband receiver was used without a rectifying detector. Although a narrow bandwidth and a rectifying detector make the signal easier for a novice to read on the oscilloscope, such processing severely reduces the true information content. In signal processing it is generally true that reduction of the information content is tantamount to summarizing the information, which emphasizes certain features of the information and ignores other information completely. Specifying such a summarization requires an understanding of the relation between the signal and the physical phenomena being analyzed. In the early stages of a project it is important to look at as much information as possible, then to make an intelligent decision as to how to process it. Utilizing a signal processing system optimized for a different purpose may well disguise the very information that is important, giving a completely misleading impression as to the capability of the method. The receiver gain was fixed throughout these experiments, which results in a reduction of the amplitude of the echoes from surfaces farther from the transducer. In a final implementation, the knowledge of the attenuation of the medium would be used to implement a varying gain that partially compensates for this attenuation, at least for an average specimen.

The area studied was about an inch below the surface of the steak. The external fat was trimmed off and the transducer aimed in the direction shown in Figure 4-2. The electronics was gated so that the picture displayed covers the range of 20 mm to 70 mm from the transducer, each graticule division being 5 mm. The same gain was used for all pictures and it was checked against the echo from a plastic block regularly throughout the experiment. The steaks were studied within 1/2 hour to 1-1/2 hours after removal from the refrigerator.

The resulting data are interpreted with the aid of Figure 4-3. A typical target is assumed to be comprised of two homogeneous substances of different density as indicated by the presence or absence of shading. The typical A-scan ultrasound echo occurs at the interface of the two substances as shown in the "typical signature" in Figure 4-3. Assuming the shaded region to be muscle and the unshaded to be fat, Figure 4-3 depicts two isolated regions of fat within a muscle surrounded by fat. If there were no fat structure within the muscle, one would expect an echo pattern as indicated in the "low fat signature" echo. Note in this pattern, the only echoes are those resulting from the muscle/external fat interfaces. If one then envisions the muscle to be filled with islands of fat, the resulting echo pattern would be as indicated in the "high fat signature" echo. This relative comparison of the "richness" of the echo is used as a qualitative indicator of marbling within the muscle.

Figure 4-4 shows one typical scan of each grade. The specimens selected were prime #35, choice #22, good #19, and standard #2. Even on a subjective basis, the echo content is seen to be greater for the better grades. This strongly supports the hypothesis that electronic processing can yield an objective readout that will correlate well with conventional visual beef grading. Prior to these experiments two samples each of a prime and a good graded roast were studied to determine a reasonable set of electronic parameters and an experimental protocol for the data. At 4°C the attenuation of the 2.25 MHz ultrasound in the 20 mm or so of fat outside the steak proved to be prohibitive. Other angulations in the muscle and other operating frequencies were tried. A 1 MHz transducer seemed to provide too poor resolution for distinctive signatures. Although there seemed to be a difference between the A-scan signature of the good and the prime at 5 MHz, the attenuation was high and the distinction at 2.25 MHz seemed just as good.

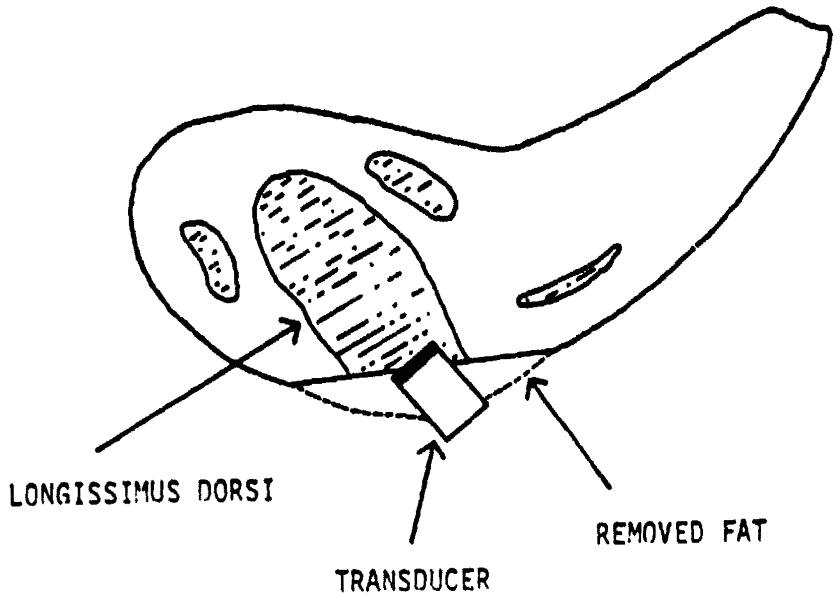


Figure 4-2. Ultrasound Transducer Position

Experiments were also conducted aiming the transducer directly into the muscle from the cut surface of the beef. There seemed to be a discernible difference among grades with the transducer at a 45° angle to the surface and even with it perpendicular to the surface, so the ultrasound propagated generally along the fiber. The latter seemed a less repeatable experiment, probably because it depended on the fibers and the marbling not being truly perpendicular to the surface throughout the depth of the meat. Although a different protocol was decided upon for the 40 steaks studied, the possibility of using echoes with the transducer on the top of the meat should not be totally discarded without further study.

One of the limitations of any ultrasonic system is its dynamic range, which is defined in terms of the ratio of the strongest signal it can provide to the weakest signal that can just be seen in the noise. For typical A-scan systems that do not employ sophisticated signal processing, this is around 100 to 120 dB. The energy of the fine echoes that are to be received in the beef was found to be approximately 30 dB below that of the incident beam. The difference of these figures leaves 90 dB for the allowable attenuation of the ultrasound during the two-way path through the meat, or 45 dB attenuation for the one-way path between the transducer and the region of interest.

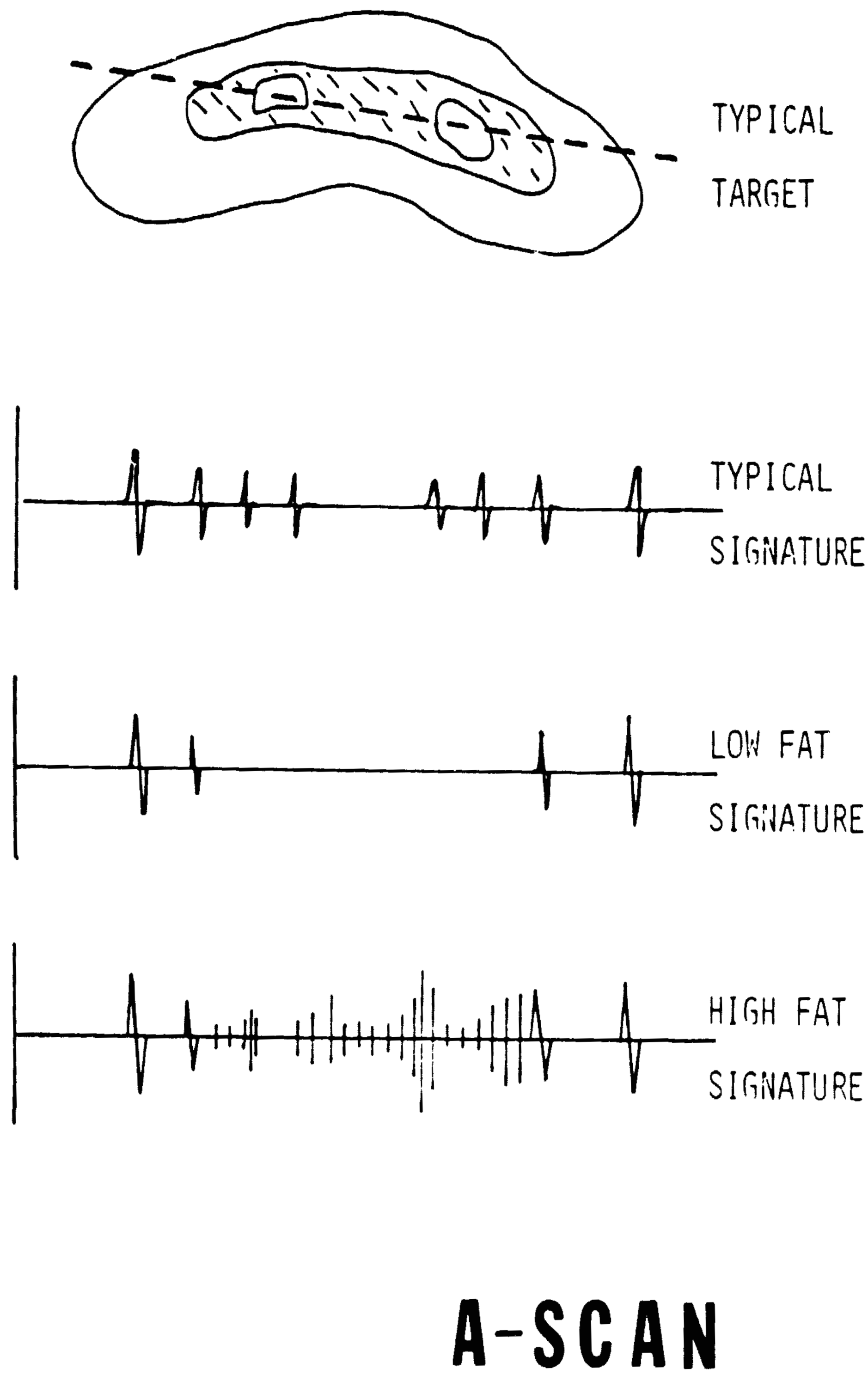


Figure 4-3. Ultrasound Echo Analysis

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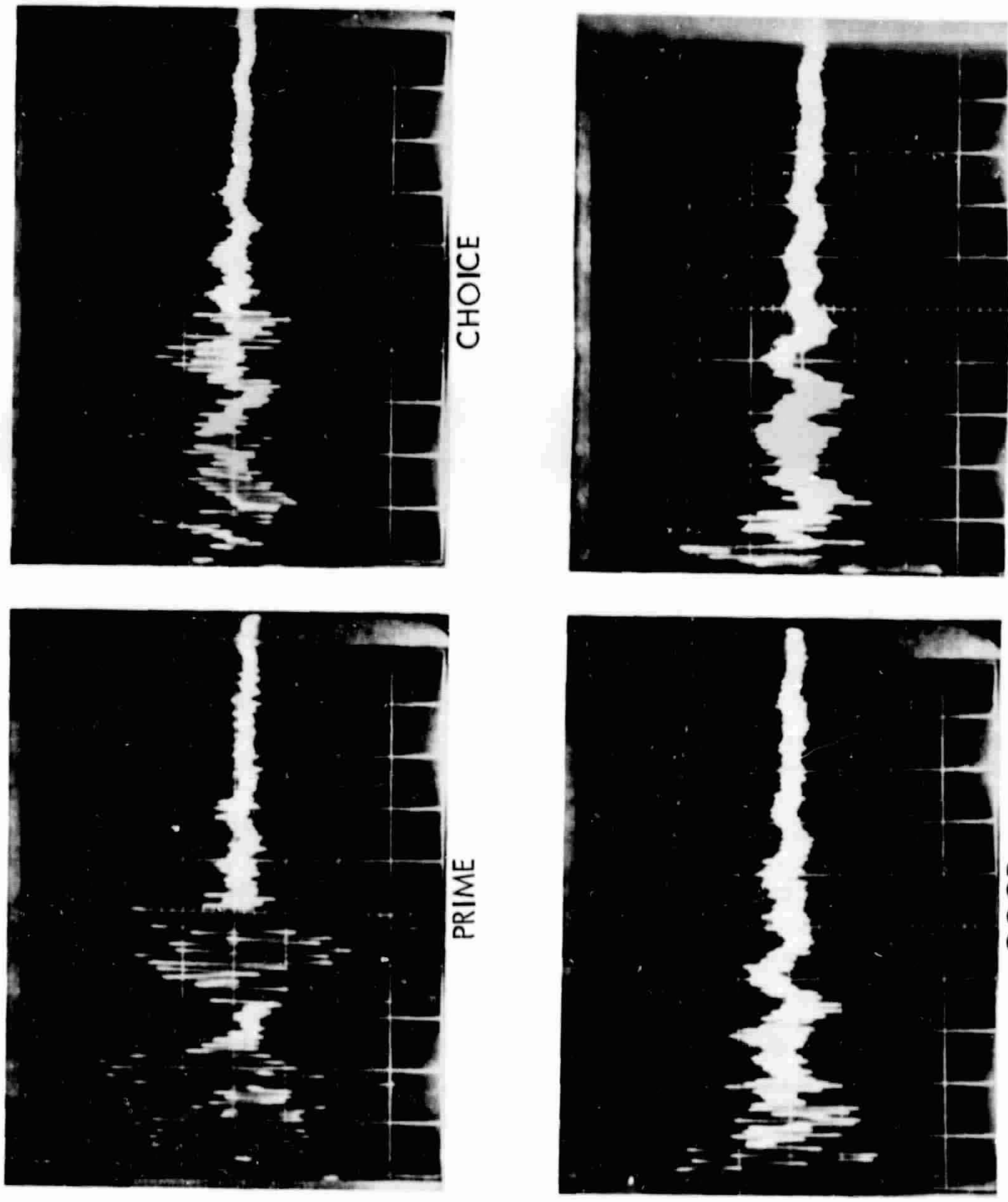

Figure 4-4. Typical Ultrasound Steak Results

In order to determine the effect of attenuation on system performance, the attenuation in beef muscle and fat was measured at several temperatures and frequencies. The results are expressed in terms of the dB attenuation per centimeter of path traveled. The attenuation perpendicular to fiber direction was measured. The attenuation in the muscle at 2.25 MHz is slightly temperature dependent, being around 6 dB/cm at 4°C and 4 dB/cm at 20°C.

The attenuation of beef fat was measured and found to be strongly temperature dependent, being much higher at lower temperatures. Since the fat is known to undergo a phase transition, it is not at all surprising that there should be a large change between 20°C and 4°C. At 20°C the attenuation in fat is around 3 dB/dm, which is less than that in muscle. At 4°C, on the other hand, the attenuation is around 16 dB/cm.

This temperature dependence of attenuation allows assessment of the range that can be achieved with a simple ultrasonic system operating at 2.25 MHz. At 20°C the maximum attenuation in either type of tissue (fat or muscle) is 6 dB/cm, so the allowable one-way attenuation of 45 dB permits a range of 7.5 cm in beef. At 4°C, however, the attenuation of the fat is so high, namely 16 dB/cm, that the range has been reduced to 2.8 cm, which is approximately the thickness of the fat layer itself in many carcasses.

Several approaches can be used to circumvent this problem of the higher attenuation on fat at lower temperatures to enable ultrasonic quality grading on chilled carcasses. The most straightforward approach is to remove most or all of the fat from an area in the side, as was done for this study. A lower frequency transducer can be used if the loss of the resolution can be tolerated. This merits investigation. The preliminary study indicated that reasonable echoes can be obtained from a transducer placed of the cut surface of the meat. Echoes can be obtained through the cellophane that is placed on the surface by the graders, provided it is in good, air-free contact with the meat. Sophisticated signal processing techniques can be used to greatly extend the dynamic range of the system. Another solution is to grade the beef after slaughter, but before chilling, to take advantage of the lower attenuation at the higher temperatures. The grading of live animals seems feasible since the decrease of attenuation with increasing temperature is probably more than adequate to compensate for the ultrasonic attenuation of the hide and coupling through the hair (with appropriate gel or water).

If ultrasound is to be used for yield grading, all of the above suggestions would apply except removing the fat and measuring with the transducer on the top surface of the muscle, both of which, of course, would not be appropriate to measuring fat thickness. Use of a lower frequency transducer (probably 0.5 MHz) and special instrumentation may be the best way to measure the thickness of the exterior fat on a cold carcass. Measurement of the internal fat such as kidney fat would be feasible only before the carcass is gutted, since afterwards there are large air spaces within the carcass.

SECTION V

RESULTS

The results presented in this report show the feasibility of accomplishing an automated grading of carcass beef using image processing and ultrasound technologies. The experiments utilized a sample of steaks with various genetic and growth characteristics including age, sex, diet, etc. Although this sample population was graded by a single individual, a senior grader of the Department of Agriculture, the results of this categorization remain subjective and susceptible to change with time and environmental conditions.

With a sample of 10 steaks in each of the grades including prime, choice, good and standard, a statistically significant test was expected. Therefore it could be concluded that the trend noted in Table 2-2 was substantial and the feasibility of utilizing the ratio of fat area to total muscle area is a useful methodology for determining marbling of the rib eye steak.

The multispectral analysis is a more complex methodology and its interpretation is more difficult. The results from earlier studies which were accomplished with fresh beef, hours after grading, showed remarkable correlation with grade and a priori knowledge of the expected distribution of intramuscular fat within the muscle. The tests with the sample of 40 steaks, not accomplished until days after being graded and held in a refrigerator, did not show the same result. Because of dehydration and, in some cases discoloration, it is felt that the multispectral analysis saw real changes which could not be associated with grade but with age after slaughter. There is still a strong motivation to continue these studies in a future program.

The ultrasound study clearly demonstrates the relationship between the qualitative appearance of marbling in the steak and the "richness" of the ultrasound signature. Although these tests were analyzed in a subjective way, the resulting data show the feasibility of utilizing the methodology for further signal analysis. The ultrasound technique also holds the possibility of studying the fat content of interior muscles on the carcass and on living animals.

In summary, two imaging methods are shown to hold the potential for measuring the marbling of a steak by analysis of the percentage fat seen at the steak surface. More detailed analysis, not conducted in this preliminary study, hold the potential of also describing the distribution of the sizes of the marbling, i.e., the distribution of the sizes of the fat areas at a given section of the muscle. The imaging analysis is felt to hold the most direct and immediate application to assist the grader. The ultrasound method may require additional studies but also holds the attractive potential of being useful on living animals or on intact carcasses.