

Effects of Retail Display Conditions on Meat Color

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This paper will deal with the effects of display conditions on meat color. Display is defined as the offering of product under lighting and at a refrigerated temperature, usually pre-packaged. Display is not the same as storage, which I define as keeping cuts in the dark and not available to the purchaser. Some studies use the word *storage* when they seem to mean *display*.

I will usually restrict this discussion to display, not storage, except where storage conditions have an effect on later display.

Factors to be covered are type of display lighting, intensity of lighting, temperature, packaging film and atmosphere within the film package. I will not deal with muscle characteristics affecting display color or shelf life or with processing, with the possible exception of modified atmosphere packaging.

Meat and Color and Its Importance

Judging color is part of our everyday life (Judd and Wyszecki, 1963). Birren (1963) has stated that everything owns its own color. He found that bright, "warm" colors of certain foods tend to stimulate the autonomic nervous system, affecting the digestive system, while soft, "cool" colors depress it. In further testing certain animals and birds were shown to react in the same manner as humans, so color is apparently a universal means of judging acceptability of food.

Factors which influence the visual appearance of meat are rapidly assessed by a consumer and interpreted into a response: to buy or not to buy; to eat or not to eat (Mackinney *et al.*, 1966). Color is probably the single greatest appearance factor that determines whether or not a meat cut will be purchased. Hiner (1954) stated that color of a product has both a psychological and a real effect on a consumer. The psychological effect occurs because color causes an almost immediate positive or negative response, and the real effect is an indication of quality, amount of time held, temperature of holding, and how the product was handled. Pangborn (1967) states that "to a large extent, man recognizes, discriminates

and selects nutrients with the eye. Through conditioning and association he expects an item of certain shape and color to have a specific odor, taste and texture." Thus the meat industry should be cognizant of consumers' preference for a certain color in meat products.

Francis (1963) stated that color in food has two general aspects. The first deals with coloring agents added to various foods while the second deals with the natural pigments such as myoglobin and hemoglobin found in meats. The former can be used to produce an appealing color, but are illegal in many areas. Natural pigment state and concentration are difficult to control because of inherent differences in muscles and animals, and because of the different physical characteristics of each animal at the time of slaughter. These include differences in age, sex, nutritional state, antemortem handling and postmortem treatment; all of which may have significant effects on lean meat color.

The importance of meat color was demonstrated by Naumann *et al.* (1957), who found that consumers consider two different preferences in their meat purchasing. One is a minimum visual appearance if the meat cut is to be bought while the other is palatability, which is determined by the overall quality of the meat. Certainly consumers have few if any means of estimating the flavor, juiciness and tenderness of a cut of meat while it is in the showcase so they must base their selection on visual appearance. Color, of course, is much of what the consumer bases his choice on.

Light Effects

There are conflicting reports on whether light discolors muscle. Ramsbottom *et al.* (1951) and Kraft and Ayres (1954) reported no difference between the color of fresh meat exposed to light and that of meat stored in the dark. However, Marriott *et al.* (1967) found discoloration of fresh beef under lighting. Santamaria (1970) and Leising (1976) also noted discoloration of frozen beef longissimus and psoas major that were displayed. Fry (1972) and Schafer (1972) reported progressive discoloration with display time for the same frozen beef muscles. Jeremiah *et al.* (1972) reported lamb leg roasts displayed under 82 foot candles of incandescent lighting to be darker after display than similar cuts stored in dark, but vacuum-packaged rib chops stored in light showed a color advantage up to 14 days over similar cuts stored in dark.

Watts (1954) postulated that fresh meats are not materially discolored by display lighting during a three-day period, but longer display may bring about discoloration "primarily due to microbial development." Rickert *et al.* (1957) and Claus *et al.* (1957) reported that light versus dark storage had little ef-

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fect on color of fresh meat. Kennick *et al.* (1971) noted color deterioration of fresh beef steaks under lighting. Steaks held in dark at 1.7°C for 24 hours had 23.8 hours less display life than those placed under display immediately after packaging.

However, Lentz (1971) found exposure of frozen beef to light at the intensity found in many retail frozen food display areas at the temperatures normally found in these areas to cause appreciable color change in 1 to 3 days and pronounced change in 2 weeks.

Bala and Naumann (1977) determined the effect of Warm White fluorescent lighting at 120 foot candles for 12 hours per day on the conversion of oxymyoglobin to metmyoglobin of a sterile, aqueous, fat-free beef extract held at 1°C. After 26 days the oxymyoglobin was completely lost in the light-exposed sample compared to a 60% loss in samples held in the dark.

We feel that light affects muscle pigment state and color, but the eye may not be sensitive enough to detect these changes early in display.

Type of Lighting

Display lighting effects could result from: 1) temperature elevation at the meat surface, 2) photochemical effect, and/or 3) differences in light rendition because of different spectral energy distribution patterns.

Brissey (1963) states that the radiant heat from intense display lighting increases temperature on the meat surface. Santamaria (1970) demonstrated a temperature elevation of about 7° and 6°C, respectively, at the meat surface from incandescent and deluxe cool white fluorescent lights compared to the temperatures of a sample kept in the dark.

Lighting engineers have recognized that deluxe fluorescent lamps radiate about 1/3 as much heat as incandescent lamps while reflective lamps with dichroic filters such as the GE Cool Beam radiate 1/3 as much heat as incandescent, for equal foot candle intensities. They also estimate about a 1°F temperature rise for each 10 foot candles of incandescent lighting for cases with a 70 cubic feet per minute air velocity. Radiant energy from the walls, ceiling and floor of the store can affect temperature even when lights are out. Warmer temperature at the muscle surface has the potential to encourage more rapid discoloration.

Concerning photochemical effects, a number of papers and reviews deal with explanation of mechanisms of muscle discoloration. It is not the purpose of this paper to deal with this topic. A review by Giddings (1977) offers a wealth of ideas and findings.

Many examples of photochemical effects exist in nature. Lighting affects a diversity of biological material. Kennedy *et al.* (1980) has shown a dose-dependent malignant transformation in a cell line derived from mouse embryos induced by soft white fluorescent lighting at an intensity of 910 foot candles (6 inches from uncovered cultures) and note a plateau in effect of time exposure similar to that shown by ultraviolet light exposure. They also cite a toxic and mutagenic effect on bacteria by fluorescent light. Sixteen hours of light daily at 114 to 207 lux increased weight gains and milk yield 10 to 15 percent in Holstein cattle compared to those exposed to natural photo-periods of 9 to 12 hours at 39 to 93 lux (Peters

et al., 1978). For growing cattle, weight gain was improved without increased feed consumption. The above examples represent just a very small part of the field of photo-biology.

Archer and Brandfield (1950) suggested that greater "destruction" of heme pigments was due to strong absorption at certain wavelengths. Setser (1972) found purified myoglobin to have sharp, well-defined absorbancy peaks at 206 nm and 408 nm and to have broader absorbancy peaks at 275, 504 and 603 nm.

In the visible spectrum, oxymyoglobin is characterized by absorption peaks at about 545 and 582 nm, reduced myoglobin by a broad absorption band with a maximum at 555 nm (green) and metmyoglobin by absorption bands with maxima at 505 and about 630 nm (Francis and Clydesdale, 1975).

Color rendition or spectral energy distribution is a concern for many businesses. Lighting is a special concern in art galleries, but is also important in stores that sell clothing, carpeting, drapery and other items requiring color matching and/or appraisal. Offices and work areas should be planned to increase worker comfort and performance. Supermarket lighting can affect customer choices, especially at the meat counter.

Lamp (bulb) selection is based on efficacy (lumens/watt), on lamp appearance effect on neutral surfaces, effect on coolness or warmth of atmosphere, on colors strengthened or greyed and on effect on complexions. Some lamps cause the complexion to look very pale, almost like that of a corpse, and others result in a more lively color (Anonymous, 1974).

Clark (1956) presented spectral reflectance patterns through the visible spectrum for 4 meat products (Figure 1) and indicated that light sources with a closer fit to the reflectance pattern for any product or muscle will bring out the natural ap-

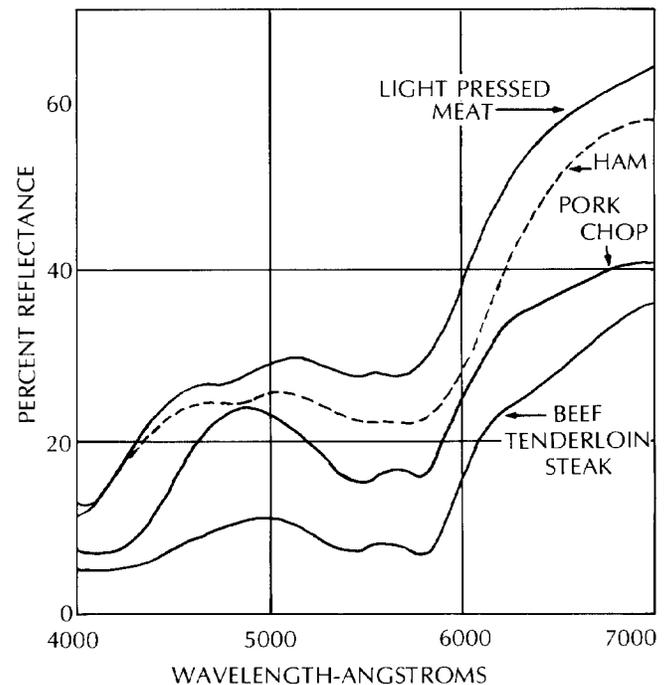


Figure 1. Spectral reflectance of several meat samples (Clark, 1956).

petizing appearance of that product. Meat light sources should be reasonably rich in the red part of the spectrum.

Figure 2 presents the spectral energy distribution of two light sources, standard cool white and deluxe cool white (Clark, 1956). Deluxe cool white has more power in the red and green parts of the spectrum and less in the violet, blue and yellow area, and of these two light sources was preferred for red meat lighting. Figures 3 and 4 show the spectral energy distribution for two light sources that we recommended based on a frozen beef muscle display study. Both have a high proportion of red emission.

Table 1 shows the measured watts and percentage of the total wattage for six arbitrary sections of the visible spectrum as well as ultraviolet and far red. The first eight light sources are fluorescent. Lowest ultraviolet output is represented by Incandescent and the highest by Soft White. Wide Spectrum Grolox is relatively high in blue while both Incandescent Fluorescent and Incandescent have low amounts of blue emission. Incandescent was found to be low in green wavelengths while Cool White, Deluxe Cool White and Deluxe Warm White were high. Extremes in yellow were shown by Cool White at 18.3% and Standard Grolox at 2.3%.

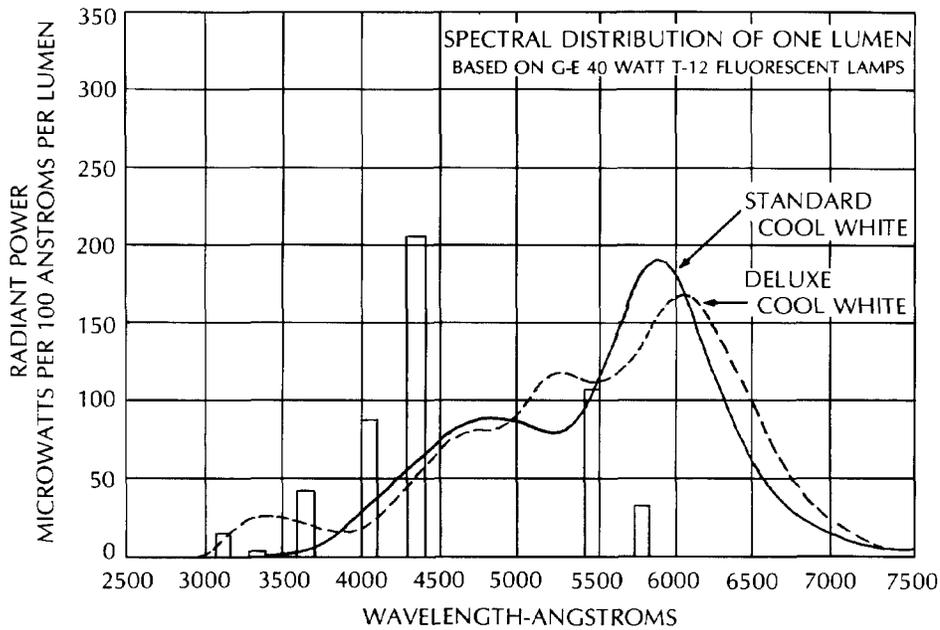


Figure 2. Spectral comparison of deluxe cool white and standard cool white fluorescent lamps (Clark, 1956).

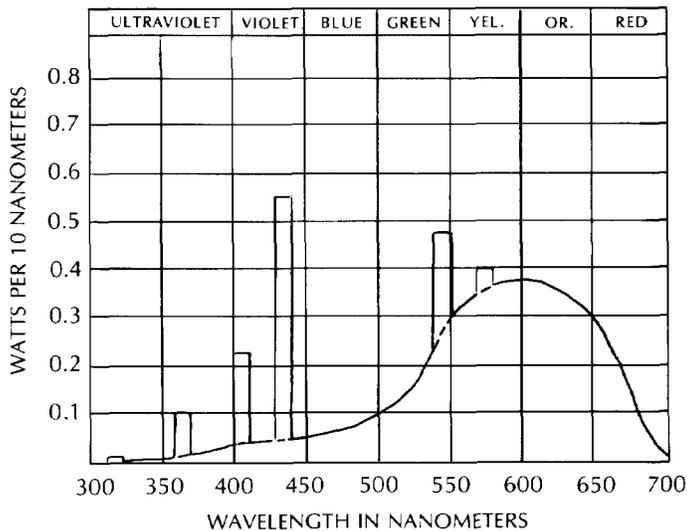


Figure 3. Warm White Deluxe F40WWX.

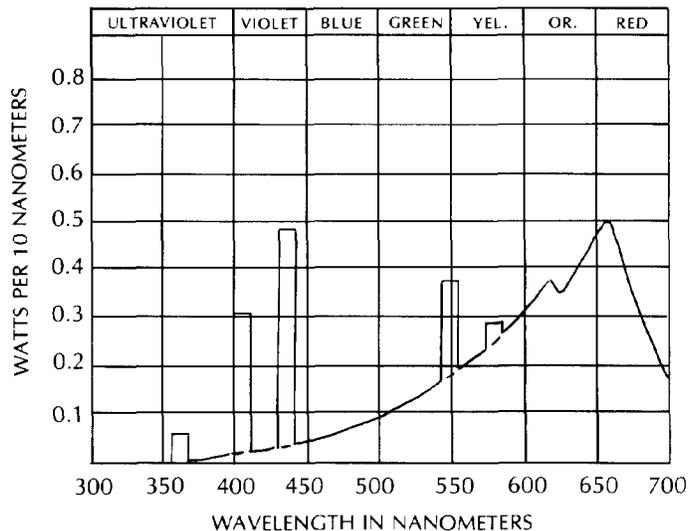


Figure 4. Incandescent Fluorescent F401F.

Table 1. Measured Spectral Energy Distribution of Nine Light Sources

	nm	Cool White		Deluxe Cool White		Deluxe Warm White		Natural		Soft White		Standard Grolox		Wide Spec Grolox		Incan. Fluores.		Incandes.	
		Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%	Watts	%
UV	<380	0.16	1.7	0.15	2.1	0.13	1.8	0.26	3.6	0.49	7.0	0.13	1.8	0.29	3.4	0.12	1.9	0.11	1.1
Violet	380-430	0.72	7.6	0.56	7.8	0.38	5.4	0.51	7.1	0.50	7.1	0.53	7.3	0.82	9.7	0.13	2.0	0.18	1.9
Blue	430-490	1.98	20.8	1.36	18.8	0.84	11.8	1.12	15.5	1.32	18.7	1.73	23.8	1.32	15.6	0.45	7.0	0.53	5.5
Green	490-560	2.35	24.7	1.73	24.0	1.68	23.7	1.54	21.3	1.47	20.9	1.10	15.1	1.18	14.0	1.04	16.2	1.25	12.9
Yellow	560-590	1.74	18.3	0.86	11.9	1.09	15.4	0.79	10.9	0.86	12.2	0.17	2.3	0.85	10.1	0.76	11.8	0.78	8.1
Orange	590-630	1.69	17.8	1.20	16.6	1.46	20.6	1.18	16.3	1.34	19.0	0.55	7.6	1.40	16.6	1.23	19.2	1.30	13.5
Red	630-700	0.81	8.5	1.36	18.8	1.52	21.4	1.83	25.3										
Total		9.52		7.22		7.10		7.23		7.05		7.28		8.45		6.42		2.91	30.1
Far Red		0.07	0.7									0.04	0.5	0.59	7.0	0.48	7.2	2.60	26.9

Standard GroLux was lowest in orange at 7.6% while other sources ranged from 13.5 to 20.6%. Red emission should have an important bearing on redness of meat, and this ranged from a low of 8.5% for Cool White to 41.6% for Standard GroLux. We consider these two light sources, respectively, to provide very poor rendition for beef muscles and to make them look misleadingly red. Lamps which have provided good color rendition in our studies and their percentage of red include Incandescent Fluorescent (34.4), Incandescent (30.1), Natural (25.3), Wide Spectrum GroLux (23.7) and Deluxe Warm White (21.4). Although the lumens were standardized, watts of output varied. The Incandescent source produced the greatest output in the far red, indicating possible temperature elevation problems. The wide variation in the above light sources indicates a potential for differences in both color rendition and color stability.

Clark (1956) emphasizes the effects of color rendition, i.e., the closeness of fit of spectral energy distribution to muscle reflectance. Undesired effects include the pinkish appearance of bone and fat under Soft White lighting, and the yellowish appearance of fat and bone under Deluxe Warm White and Incandescent. Barr *et al.* (1952) had earlier reported similar effects for Soft White and for Incandescent and recommended Deluxe Cool White for the white fat color it promoted.

As another example of effects of color rendition, beef carcasses evaluated under Incandescent and "Optima" fluorescent lights were rated less mature than those rated under Cool White fluorescent light (Hoke and Davis, 1969), but the maximum difference amounted to only 3.3% of a maturity grade. Hoke and Davis (1970) reported color scores of 4.18,

4.37 and 4.64, respectively, for Incandescent, Deluxe Warm White and Cool White ($P > .05$ for all comparisons) where 4 = cherry red and 5 = slightly dark red.

Table 2 summarizes work on effects of segments of the electromagnetic spectrum on muscle discoloration. Results conflict on effects of UV, green or orange parts of the spectrum, but blue or yellow light seems to encourage color deterioration, especially of frozen samples. Unfrozen muscle may be less affected than frozen.

Table 3 summarizes studies on effects of type of meat display lighting and shows a variety of results. I will summarize some of our studies at Kansas State University in more detail.

Fry (1972) studied the effect of ten different commercial light sources on color stability of frozen beef longissimus and psoas major frozen in a simulated liquid nitrogen freezer, skin-tight packaged in lolon film of medium oxygen permeability, when tested at 72°F (22.2°C) and displayed under 100 foot candle light intensity at either -5°F or -15°F (-20.6° or -26.1°C). Color was evaluated visually and by reflectance spectrophotometry at 0 time and after 1, 3, 7, 21 and 35 days of display. Table 4 presents visual color scores of two different scorers after 7 days of display as evaluated under display light and also as scored under two common light sources, namely Deluxe Cool White and Incandescent, to visually determine if differences were due to color rendition or to "real color deterioration." Scorers judgments are affected somewhat differently by light source used for evaluation. Fewer treatment differences were noted when all were evaluated under either Deluxe Cool White or Incandescent, and brighter color was noted under Incandescent. Generally,

Table 2. Effect of Light Wavelength on Muscle Discoloration

<i>Authors</i>	<i>Light</i>	<i>Effect</i>
Archer and Brandfield (1950)	Blue and green	Greatest destruction of "heme pigments"
	Filters of low 400 nm range	Increased time to discoloration
Ramsbottom <i>et al.</i> (1951)	UV filters for fluorescent lights	No effect on discoloration
Kraft and Ayres (1954)	UV radiation	Primarily desiccation of cellophane-wrapped beef round steak @ 2.5°C
Kampschmidt (1955)	350 to 580 nm	More discoloration than longer wavelengths
Townsend and Bratzler (1958)	Yellow and orange (560 to 630 nm)	Degrade color of frozen beef longissimus @ 0° F (-17.8°C)
	Green or red	More stable color
Solberg and Franke (1970)	420, 510, 550, 570, 590 and 632.8 nm light @ 0.5 ₂ milli-watt per cm ²	No specific wavelength enhanced metmyoglobin production compared to others @ 34° and 41°F (1.1° and 5°C) for 2 inch cores of choice beef adductor and semimembranosus

Table 3. Summary of Type of Lighting Effects on Muscle Color or Color Evaluation

<i>Authors</i>	<i>Light source(s)</i>	<i>Effects</i>
Haurowitz (1950)	Incandescent, tungsten filament and fluorescent (unspecified)	All cause same degree of "fading" of color on fresh and cured meat surfaces
Ramsbottom <i>et al.</i> (1951)	Fluorescent (unspecified) compared to UV at 60 foot candles	Fresh meat not discolored after 36 hours of fluorescent, but changed by UV
Kraft and Ayres (1954)	UV radiation	Primarily desiccative on cellophane wrapped round steak @ 2.5°C
Clark (1956)	Deluxe cool white, deluxe warm white, soft white and incandescent	Superior for color rendition
Townsend and Bratzler (1958)	Yellow portion of spectrum from white fluorescent lamps	Causes frozen meat discoloration due to metmyoglobin formation
Hansen and Sereika (1969)	Incandescent, cool white, deluxe cool white, warm white, deluxe warm white, soft white natural and wide-spectrum lamps	No difference in effect on frozen beef "short loin" steaks at -23.3°C (-10°F)
Fry (1970)	Compared ten commercial light sources at 100 foot candle intensity	For beef longissimus and psoas major at -5° or -15°F (-20.6° or -26.1°C) in skin-tight lolon film, standard Grolux resulted in a too red, misleading color; best color rendition resulted from Grolux wide spectrum, incandescent fluorescent, incandescent, cool beam and deluxe warm white with very poor color rendition from cool white. Best color from Grolux wide spectrum, incandescent fluorescent and deluxe warm white.
Santamaria (1970)	Incandescent and deluxe cool white at 0, 75, 100, 150 and 300 foot candles for display and at 100 foot candles for evaluation	Longissimus and psoas major displayed at -21°C had color score affected by light source
Satterlee and Hansmeyer (1974)	Fluorescent light with higher proportion of light from shorter wavelengths @ 250 foot candles	Accelerated oxidation of oxymyoglobin in beef semitendinosus exposed @ 5°C and packaged in polyvinyl chloride
Hunt <i>et al.</i> (1975)	Deluxe cool white versus incandescent (Holophane Prismatic lens)	Visual scores and reflectance data did not always agree for lamb chops. Authors suggest the incandescent light source may mask color deterioration

Table 3. (Continued)

Authors	Light source(s)	Effects
Lentz (1979)	Cool white and deluxe warm white fluorescent Outdoor northern exposure, fluorescent or incandescent at 500 to 2500 lux	Beef biceps femoris and semitendinosus were not affected in preliminary work (not well described) Did not affect comparison of Munsell chips or chips to meat samples in preliminary testing

Table 4. Effect of Type of Lighting on Visual Color Score of Frozen Beef Muscle

	Display Light ^a		Deluxe Cool White ^a		Incandescent ^a	
	7F	7K	7F	7K	7F	7K
Deluxe warm wh.	3.51 ^{def}	2.95 ^b	3.44 ^{abc}	3.04 ^a	2.83 ^{bcd}	2.66 ^a
Grolux wide spec.	3.15 ^{ab}	2.96 ^b	3.24 ^a	3.09 ^a	2.60 ^a	2.75 ^{ab}
Incan. fluor.	3.38 ^{cd}	3.04 ^{bc}	3.35 ^{ab}	3.15 ^a	2.80 ^{abc}	2.71 ^a
Std. Grolux	3.20 ^{bc}	2.68 ^a	3.33 ^{ab}	3.11 ^a	2.70 ^{ab}	2.86 ^{bc}
Deluxe cool wh.	3.45 ^{de}	3.40 ^f	3.45 ^{abc}	3.40 ^b	2.86 ^{bcd}	2.98 ^c
Verda-ray Fadex	3.59 ^{ef}	3.35 ^f	3.60 ^{cd}	3.31 ^b	3.04 ^{ef}	3.06 ^d
Cool white	3.66 ^f	3.75 ^g	3.66 ^d	3.36 ^b	2.96 ^{cdef}	3.06 ^d
Soft white	3.48 ^{def}	3.31 ^{ef}	3.59 ^{cd}	3.41 ^b	3.01 ^{def}	3.13 ^d
Incan. holophane	2.98 ^a	3.13 ^{cd}	3.51 ^{bcd}	3.36 ^b	2.98 ^{cdef}	3.13 ^d
Cool beam	3.19 ^{bc}	3.19 ^{de}	3.45 ^{bc}	3.45 ^b	3.13 ^f	3.06 ^d

^aEvaluation lighting

^{b-h}Means in any column same superscript letter are not different ($P > .05$).

Combined Means: L and PM, -20.6 and -26.1 C.

less desirable color was noted after 7 days of display for Deluxe Cool White, Verda Ray Fadex, Cool White, Soft White, Incandescent and Cool Beam commercial light sources.

The complexity of the light source data, especially when one considers results after various display times have led us to the summary of Table 5 (Tuma *et al.*, 1973). These ten light sources were scored for both color balance or rendition and for color stability of frozen beef muscles in skintight film under these display conditions. The Standard Grolux is very red, as would be expected by its high percentage of red emission (Table 1), and we feel that this redness is misleading and could mask muscle color deterioration. Cool White results in a very blue, discolored appearance of muscle and does not have enough red emission to bring out the natural color. Such lighting puts red meat products at a disadvantage in the market place. Unfortunately, much general store lighting is Cool White. Soft White and Deluxe Cool White also are poor sources for meat display. However, Deluxe Cool White is frequently used for meat case lighting, and its only advantage is the white color imparted to fat. The other six light sources we tested seemed excellent in color emission balance for muscle, but Deluxe Warm White and Incandescent Fluorescent cause a slight yellow fat color which may be a serious merchandising problem in some market areas.

Incandescent and Cool Beam lighting also tend to impart a yellow color to fat of frozen beef cuts. Light sources were also

given a score for color stability which we feel is somewhat independent of color balance. Our study was not designed to determine harmful wavelengths, and from the light emission data it is difficult to find unique and common reasons for the

Table 5. Effect of Ten Commercial Light Sources on Color of Frozen Beef Muscles

Light Source	Color Balance ^a	Color Stability ^b
Deluxe warm white ^c	++	+
Grolux wide spectrum	++	++
Incandescent fluorescent ^c	++	++
Standard grolux ^d	+++	+
Deluxe cool white	-	0
Verda-ray	++	0
Cool white	--	-
Soft white	-	-
Incandescent holophane ^e	++	0
Cool beam ^e	++	0

^aColor Balance +++ reddest, ++ excellent, + good, - poor, -- exceptionally poor.

^bColor stability ++ best, + good, 0 fair, - poor.

^cSlight yellow fat color

^dToo red, misleading

^eUneven intensity

poorer stability of Cool White and Soft White. Soft White is high in UV percentage and Cool White is high in yellow.

For frozen beef muscle, more specifically longissimus (a white muscle) and psoas major (a red muscle) we believe type of lighting can affect color rendition and muscle color stability. Light source used for color evaluation can definitely affect visual scores.

We have also done a study of lighting effects on wafer sliced cooked and cured beef in a nitrogen flush package. Product fading was evaluated after 6, 12, 24, 48 and 72 hours under Deluxe Warm White, Supermarket White, Incandescent Fluorescent or Natural lamps at four lighting intensities and three display temperatures. Product under Supermarket White consistently showed more visual fading, but this was not confirmed by reflectance data. We concluded that these differences were due to color rendition.

Soft White and Warm White fluorescent lighting at 250 to 300 foot candles caused larger rate constants for autoxidation of purified oxymyoglobin from bovine, ovine and porcine than for dark controls when all were held at -19°C in 10 mM phosphate buffer at pH 6 (Satterlee and Zachariah, 1972). Pink or red fluorescent lighting or Incandescent did not increase autoxidation rate constant. The authors concluded that "low wavelength light" encourages autoxidation but 625 nm or longer wavelengths are not easily absorbed by the oxymyoglobin molecule.

In summary, type of lighting can affect red meat appearance and shelf life and should be chosen to optimize both.

Lighting Intensity

Ramsbottom *et al.* (1951) found discoloration rate of fresh meat at 60 foot candles to be between 2 and 3 times as fast as at 20 foot candles.

Kraft and Ayres (1954) reported Soft White fluorescent light intensity to be unimportant in causing discoloration of fresh beef. Gould (1963) reported that higher intensities of incandescent light which contributed to increased surface temperature caused more rapid discoloration of fresh pork chops. Light intensities which caused no temperature elevation had no effect on discoloration rate.

Marriott *et al.* (1967) found beef short loin steaks (muscle not specified) stored at -1°C for 10 days in the dark to change only slightly in visual color while steaks illuminated continuously by 120 foot candles (fc) of Soft White fluorescent light discolored markedly after 5 days when packaged in 75 gauge polyvinylchloride (PVC). Steaks displayed under the above light after 3, 5 or 7 days of dark storage had more visual color deterioration than did dark controls. Their color became progressively worse with longer display.

Color stability of frozen beef was related to foot candle hours of illumination and length of dark storage prior to display (Naumann *et al.*, 1957). Hansen and Serrika (1969) studied color stability of frozen beef at 50, 100, 200 and 400 foot candles of Cool White fluorescent lighting and reported the 400 foot candle level to be very deleterious to color stability. They found "no difference in surface temperature of frozen beef under these lighting intensities as measured by thermocouple."

Santamaria (1970) displayed beef longissimus and psoas

major from loins with a "small" degree of marbling at 0, 807, 1076, 1614 and 3228 lumens/meter² (0, 75, 100, 150 and 300 foot candles) under either Deluxe Cool White Fluorescent or Incandescent lighting with a Holophane Prismatic Reflectance lens. Steaks had been bloomed at least 30 minutes before rapid freezing in a liquid nitrogen simulator freezer at -18°C for $\frac{1}{2}$ min, -60°C for $\frac{1}{2}$ min, -87°C for 1 min, -115.7°C for 1 min, -143°C for 1 min and 1 minute tempering. After freezing, steaks were skin-tight packaged in DuPont lonol film. The maximum surface temperature difference between the four lowest light intensities was about 3°C , but the highest intensity of Incandescent lighting consistently elevated meat surface temperature 7°C above that of the dark-stored steaks when case temperature was -21°C . Color was evaluated under a similar light intensity and under both light sources for all muscles. The highest light intensity caused the most rapid color deterioration after 1, 3, 7, 21 and 42 days, while muscles stored in dark showed excellent color stability. The 807 lumen/m² was superior to 1614 after all display times for both muscles. Visual observations were supported by some reflectance measurements. Samples under the Incandescent lighting system tended to show brighter color after 1, 3, 7 and 21 days of display at the 807 and 1076 lighting intensity and darker color at the highest display lighting intensity.

Lentz (1979) studied the effect of light intensities of 0, 20, 50, 100, 250, 500, 1000 and 2000 lux (10.76 lux = 1 foot candle) for frozen beef biceps femoris and semimembranosus bloomed 20 minutes and packaged in highly oxygen-permeable polyethylene before freezing in a blast freezer (2.5 m/sec) at -29°C . Display was conducted under both Cool White and Warm White fluorescent lighting and at temperatures of -7° , -18° , -29° and -40°C (Table 10). Color of muscles was assessed by matching to Munsell color chips after 1, 2, 3, 5, 10, 15, 20, 30, 40, 60 and 90 days' exposure. Greater light intensity caused reduced color stability at the -7° , -18° and -29°C temperatures. At -40°C , color was not affected by light intensity.

In a recent Kansas State University study, we compared the effect of display lighting intensity on color fading of wafer-sliced cooked and cured beef in a nitrogen flush package and noted increasing color fading with increasing foot candles (100, 150, 200 and 300) after 12, 24, 48 and 72 hours of display. This was confirmed by increasing ratios of % reflectance at 570 nm over % reflectance at 650 nm.

Our studies have led us to conclude that high-intensity lighting can reduce display life of frozen and gas-flushed product and to recommend 100 foot candles of lighting intensity or less (Tuma *et al.*, 1973). We recognize the need for about 75 foot candles or more for an effective display. Most fluorescent lighting can be arranged for uniform intensity, but Incandescent and spot lighting do not lend themselves to uniform lighting intensity.

Light intensities in retail food markets ranged from 105 to 260 foot candles as reported by Satterlee and Hansmeyer (1974) and from 22 to 350 foot candles in a survey by Rice (no date) and from 22 to 250 foot candles as noted by Schwermann (1979). This wide variation indicates a lack of awareness of effects of intense lighting on meat appearance.

Panelists rated beef carcasses more youthful at 30 than at 5

foot candles (Hoke and Davis, 1969), but the difference was 3.7% of a maturity grade. In a later study comparing 14, 50 and 100 foot candle lighting (Hoke and Davis, 1970), greater light intensity resulted in a lighter, brighter muscle color score.

The above study points out a need for evaluation of all treatments under a common lighting intensity in any study involving different light intensities.

Lighting intensity has been given in a variety of units, with foot candles the commonly used unit.

The following definitions and formulas may be helpful:

$$\text{lux} = \text{microwatts per cm}^2 \times 10$$

$$1 \text{ lux} = 1 \text{ meter candle}$$

$$1 \text{ foot candle} = 10.76 \text{ lux}$$

$$\text{foot candles} = \frac{\text{efficacy} \times \text{total lamp wattage}}{4 d^2}$$

if d = distance from lamp to illumination point

Foot candle measurements undermeasure blue and red parts of the spectrum. Table 6 presents conversion factors for several light sources to correct for that discrepancy.

This should be considered in research comparing monochromatic light sources so as to provide a basis for standardizing spectral energy intensity.

Table 6. Conversion Factors, Footcandles to Microwatts per cm² (380 to 800 nm)

Lamp	Microwatts/cm ² per footcandle
Cool white fl. (40 watt)	3.18
St. GroLux (40 watt)	7.41
GroLux wide spec. (40 watt)	4.87
Incandescent (500 watt)	6.84

Temperature

Much of the earlier work dealing with temperature effects involves storage rather than display. This is especially true for frozen products.

Low storage temperature depressed enzyme activity, minimized color changes, inhibited oxidation and reduced desiccation and drip (Ramsbottom and Koonz, 1941). Watts (1954) and Bratzler (1955) noted that oxidation rates doubled for every 10°C rise in temperature.

Snyder (1964) compared 6°, 2° and -2°C storage temperatures for fresh beef and found greater redness at lower temperatures. Because of the short storage time and slower discoloration, he discounted the microbial role and indicated decreased respiratory activity as the major reason.

Doordan *et al.* (1969) found more rapid discoloration of beef short loin and rib steaks at 38°F. (3.3°C) than at 30°F (-1.1°C) when packaged in one of 6 films and displayed under 120 foot candles of unspecified fluorescent lighting.

Lanier *et al.* (1977) used lean beef semitendinosus wrapped in polyvinyl chloride film and reported an increase rate of

metmyoglobin formation and a more rapid loss of desirable visual color with increasing temperature (0°, 2.2°, 4.4° and 6.6°C) and more rapid air movement (0.25, 0.51 or 0.76 meter per second).

We have been observing a central retail meat cutting operation in Topeka, Kansas quite closely and have been able to observe results frequently since location of a retail outlet in Manhattan, Kansas. They claim an acceptable product life for ground beef of up to 10 days with up to 5 days of this under display. Their success is due largely to very strict temperature control: in the cutting plant, in truck transport, and in the retail store holding cooler and display cases. Temperatures in their cutting plant have been observed to be close to 30°F (-1.1°C) and are several degrees cooler in their retail cut assembly and inventory area in the central meat plant. Meat display case temperatures commonly vary about 4.5°C from the air inlet to the air discharge. Higher shelves in multiple shelf cases are frequently warmer than lower shelves.

Bovine, ovine and porcine oxymyoglobin autoxidation rate increases dramatically with higher temperature in the range of 10° to 35°C (Satterlee and Zachariah, 1972).

Hutchins, Lui and Watts (1967) found large differences within muscle systems in regard to their initial reducing activity at different temperatures. Attainment of 50% reduction of metmyoglobin at 30°C took less than one hour. At 9°C it took 7 hours and at 0°C, 48 hours.

Snyder and Ayres (1961) and Brown and Dolev (1963a) found that temperature has a profound effect on oxidative reaction rates. They reported doubling the rates by increasing the temperature from 0°C to 4°C. Further studies by Brown and Dolev (1963b) attempted to show effects of temperatures below 0°C on oxidation rates. They found that all myoglobin solutions oxidized more slowly at -5°C than at 0°C but when held at -10°C the solutions were frozen and the oxidation rates increased. They concluded that this was due to physical changes involved in freezing, and probably involved adjustment of the physical proximity of the myoglobin and oxygen molecules to a distance more favorable for oxidation reactions to occur. Brown and Mebine (1969) studied temperature effects on oxidative reaction rates and showed 40 to 50 fold slower rates at -2°C than at +22°C.

Satterlee and Zachariah (1972) determined autoxidation of oxymyoglobin from bovine, ovine and porcine sources at 4°C to be affected by 1100 foot candles of soft white fluorescent lighting, but the increase was less than at 24°C in the dark. Zachariah and Satterlee (1973) found porcine, ovine and bovine oxymyoglobin to be at least stable at -11° to -12°C when studying the temperature range from -5° to -28°C. This leads to concern about frozen muscle surface appearance at such elevated temperatures. Although these temperatures should not occur during reasonably cold frozen display, they could be encountered during case defrost.

Santamaria (1970) noted that when air inlet temperatures of display cases reached as high as +6° to +10°C during defrost, meat surface temperatures reached as high as -9° to -7°C and half radius probe temperatures reached -10° to -8°C for very short periods. Thus, case defrost allows meat surface temperature to reach these points of greatest myoglobin instability, at least on the meat surface where product external color is determined.

Table 7. Effect of Display Temperature on Visual Redness^y of Frozen Beef Longissimus and Psoas Major^z

	Display, Days				
	0	1	7	21	42
Longissimus					
Display Temp					
-28.9°C(-20°F)	1.47 ^a	1.40 ^a	3.06 ^a	3.47 ^a	3.92 ^a
-20.6°C(-5°F)	1.62 ^a	1.87 ^b	3.32 ^b	3.70 ^b	4.07 ^{ab}
-12.2°C(+10°F)	1.54 ^a	2.10 ^b	3.60 ^c	3.96 ^c	4.23 ^b
Psoas Major					
Display Temp.					
-28.9°C(-20°F)	3.11 ^a	3.08 ^a	3.68 ^a	3.90 ^a	4.21 ^a
-20.6°C(-5°F)	3.04 ^a	3.29 ^{ab}	3.87 ^{ab}	4.07 ^b	4.32 ^a
-12.2°C(+10°F)	3.22 ^a	3.54 ^b	4.04 ^b	4.39 ^c	4.65 ^b

^{a,b}For a given muscle, means in same column with same superscript letter are not different ($P > .05$).

^yVisual redness: 1 = very bright red, 2 = bright red, 3 = slightly dark red, 4 = dark red, 5 = extremely dark red.

^zfrom Sandberg (1970).

Ramsbottom and Koonz (1941) stored beef rib steaks at -12.2° and -34.5°C and found faster oxidation at the higher temperatures. Ramsbottom (1947) stated that, with storage time ranging from 0 days to 365 days, as storage temperature decreased from -3.3°C to -28.9°C, color stability of pork chops increased. At -3.3°C complete discoloration occurred by 60 days while appearance of steaks remained acceptable for 90 days at -12.2°C. The two lower temperatures (-23.3°C and -28.9°C) maintained acceptable color in pork chops stored up to 365 days. Hankins and Hiner (1941) reported that color stability of freshly cut pork stored 10 months at -7.8°C decreased significantly faster than the color stability of similar cuts stored at -17.8°C.

Lentz and L. Van De Berg (1957) worked with chicken and turkey muscle and found results similar to those reported for red meat. A storage temperature of -28.8°C maintained a more acceptable color for the entire 12 weeks of the study than a temperature of -18.8°C.

Sandberg (1970) studied the effect of display temperatures of -28.9°, -20.6° and -12.2°C on color stability of beef longissimus and psoas major skintight packaged in lolon film and displayed under 100 foot candle intensity of Deluxe Cool White fluorescent lighting. The display cases at the two lower temperatures were subject to twice daily rapid defrost. All lighting was turned on 12 hours per day with case covers used when lights were off. After 1, 7, 21 and 42 days of display, higher display temperature resulted in a darker color for both longissimus and psoas major (Table 7).

If these color scores are plotted with time to determine approximate number of days of shelf life (Table 8), the longissimus had longer shelf life than the psoas major and colder display temperatures added more days for longissimus than for psoas major. However, colder display seems critical for a reasonable shelf life for psoas major.

Hunt *et al.* (1975) found lamb chops that were displayed in transparent film (either Cry O Vac L-300 or Saran) to have superior visual color and higher 630 nm reflectance when initially frozen at -40°C as compared to -26°C. He also re-

ported superior color for lamb chops displayed at -29°C compared to -21°C. Chops were displayed under 100 foot candles of either Incandescent or Deluxe Cool White fluorescent lighting for 42 days (24 hours lighting each day). The superior appearance was also noted after unpackaging and thawing.

Santamaria (1970) included two different display temperatures in his study (Table 9) and found that display at -26.1°C overcame much of the effect of more intense lighting, especially for the longissimus, when compared to -20.6°C display.

Table 8. Days to Unacceptable Color^a for Frozen Beef Muscle in Skin-Tight lolon Package

Display Temp.	Longissimus	Psoas Major
-12.2°C(+10°F)	25 (7)	7 (1)
-20.6°C(-5°F)	39 (14)	16 (4)
-28.9°C(-20°F)	>42 (22)	31 (5)

^a4 on KSU scale.

(7, etc.) = 3.5 on KSU scale.

Table 9. Days to Marginal Unacceptable Color Score (3.5) for Frozen Beef Longissimus (L) and Psoas Major (PM)

foot candles	-20.6°C(-5°F)		-26.1°C(-15°F)	
	L	PM	L	PM
300	14	7	42	21
150	19	9	>42	26
100	28	12	>42	27
75	37	17	>42	26
0	42	42	>42	42

from Santamaria (1970)

Table 10. Color Shelf Life, Days Frozen Beef Biceps Femoris and Semimembranosus

lux	-7°C	-18°C	-29°C	-40°C
0	15-30	>90	>90	>90
20	10-15	30	>90	>90
50	10-15	10-30	30-90	>90
100	10	5-10	10-30	>90
250	1-3	2-10	10-30	>90
500	1-3	1-3	10-30	>90
1000	1	1-3	15	>90
2000	>1	1	3-15	>90

from C. P. Lentz (1979).

Lentz (1979) exposed frozen beef steaks to Cool White fluorescent lighting of 150 to 200 foot candles and temperatures of -40°, -29°, -18° and -7°C (-40°, -20°, 0° and +20°F) and found colder temperatures to slow the rate of deterioration. Differences in frozen muscle color became less pronounced after thawing.

Effects of fluctuating storage temperatures have been studied by several researchers. Hustruld *et al.* (1949) stored one sample of ground beef at -18.8°C constantly for six months and fluctuated the temperature of another sample between -18.8°C and -23.4°C. They reported no significant differences between the two in regard to color, texture, and degree of desiccation. Winter *et al.* (1952) found that fluctuating temperatures between -17.7°C and -12.2°C resulted in decreased color values when compared to a constant storage temperature of -17.7°C. Townsend and Bratzler (1958) and Brissey (1963) indicated decreased color stability in meat stored at fluctuating temperatures and cyclic defrost temperatures, respectively.

Tuma *et al.* (1973) found that use of night covers for 14 hours each day (including twice daily defrost times) did not appreciably affect average visual scores for frozen beef longissimus and psoas major displayed at -5°C under 100 foot candles of Deluxe Cool White lighting. Nightcover use was expected to overcome possible negative effects of surface temperature elevation during defrost. Therefore, the above results were not expected.

Packaging

The primary function of a meat package is to present the product to the consumer in the most attractive manner possible and at the same time protect the product from physical damage, microbial deterioration and chemical change (Mills and Urbin, 1960). Color, as seen through a film, depends on the physical characteristics of the film including opaqueness, translucence, glossiness, matteness and the degree of wrinkling that occurs when the film is used (Mackinney *et al.*, 1966). Color of meat products packaged in film also depend on film gas permeability and to a limited degree on a sufficiently low moisture permeability to eliminate meat surface desiccation. Results from studies comparing packaging films are largely affected by gas and moisture permeability. Pigment stability in intact meat, according to Satterlee and

Hansmeyer (1974), involves many factors such as oxygen penetration, microbial growth, fat oxidation, the presence of flavin compounds and oxygen permeability of the film.

Westerberg (1971) reviewed packaging films and meat color for the Reciprocal Meat Conference and stated the special requirements for packaging fresh retail meat cuts, processed meats and primal and subprimal meat cuts. He indicated the importance of the bright red oxymyoglobin color for fresh retail meat cuts, although this approach has been challenged.

Sacharow (1974) has an excellent review of fresh meat packaging materials, properties and requirements. He recommends a film oxygen permeability of 5000 ml O₂/m²/24 hr/atm at 75°F (24°C) (with 100% relative humidity inside the package and 52% relative humidity outside) to maintain the red "bloomed" color.

Doordan *et al.* (1969) compared six oxygen-permeable films for fresh beef steak display and found no pattern to indicate desirability of any single film regarding product appearance. These films were reasonably similar in oxygen permeability.

Mills and Urbin (1960) indicated that packages for frozen meat must maintain desired product characteristics at freezer temperatures and be able to hold up for prolonged "storage periods." Kropf (1971) indicated the need for some oxygen permeability, even for frozen meat packaging, especially for beef, if a bright red color is desired. Lentz (1979) stated that oxygen permeability of packaging film did not appear to affect frozen beef color stability, but failed to document this statement.

Sandberg (1970) compared three films, namely a nylon film with low oxygen permeability of about 4.65 cc O₂/m²/24 hr/atm, a "medium" permeable lolon film at 209 cc O₂/m²/24 hr/atm, and a "high" permeability film of 465 cc O₂/m²/24 hr/atm, for frozen skin-tight packaged beef T-bone steaks. All permeabilities are for 72°F (22.2°C) with oxygen transmission at freezer temperatures unknown. Longissimus packaged in the low permeability film was darker in color after 1, 7, 21 and 42 days of display indicating that the other two films allowed more oxygen permeation which resulted in a brighter color (Table 11). Film differences were not found for psoas major except at 7 days. Apparently none of the films allowed enough oxygen permeation to allow a bright color.

Hunt *et al.* (1975) noted a brighter visual color after 1 and 42 days of display for frozen lamb chops packaged in oxygen-permeable L-300 film compared to that packaged in Saran, a relatively impermeable film. A higher % reflectance 474 nm/525nm for Saran packaged cuts indicated presence of more reduced myoglobin.

Sandberg (1970) reported that beef psoas major packaged before freezing was darker in color immediately after freezing and after 1, 7 and 21 days of display (Table 12). Longissimus packaged before freezing was darker after 7 and 21 days of display. The darker color likely resulted from pigment conversion to reduced- or met-myoglobin due to reduction of within-package partial oxygen pressure in the time before freezing. This suggests that a rapid freezing of packages is necessary as soon as possible after package sealing. Kropf and Smith (1973) studied the effect of bloom time and packaging time on color of frozen beef longissimus and psoas major

Table 11. Effect of Film Permeability on Visual Redness Scores^a of Frozen Beef Longissimus and Psoas Major Packaged in Skin-Tight Iolon Film

Muscle and Film O ₂ Permeability	Display Day				
	0	1	7	21	42
Longissimus					
Low	1.57 ^b	2.07 ^c	3.72 ^c	3.90 ^c	4.21 ^c
Medium	1.44 ^b	1.57 ^b	3.06 ^b	3.57 ^b	3.97 ^b
High	1.62 ^b	1.74 ^b	3.19 ^b	3.67 ^b	4.04 ^b
Psoas Major					
Low	3.18 ^b	3.46 ^b	4.19 ^c	4.24 ^b	4.49 ^b
Medium	3.07 ^b	3.24 ^b	3.69 ^b	4.03 ^b	4.33 ^b
High	3.12 ^b	3.22 ^b	3.71 ^b	4.10 ^b	4.36 ^b

^a1 = very bright red, 2 = bright red, 3 = slightly dark red, 4 = very dark red, 5 = extremely dark red.

^{b,c}Means within muscle and day with same superscript letter are not different ($P > .05$).

under display conditions. These two factors were not of great importance for the longissimus when comparing bloom times of 5, 15, 30 and 90 minutes and packaging before freezing or vice versa. Psoas major packaged before freezing in Iolon film in the skin-tight package was darker initially (after packaging and freezing) and after 1, 3 and 36 days of display. Longer bloom times were needed to avoid darker color of psoas major after packaging-freezing and after 1 day of display. The oxygen uptake of bloom time has some carryover value in keeping sufficiently high partial oxygen pressure in the package environment, at least early in display.

Pierson *et al.* (1970) noted little difference in myoglobin chemical state patterns for beef semimembranosus kept under aerobic conditions for 2 or 6 hours prior to anaerobic packaging. A 24 hour aerobic period caused more metmyoglobin which persisted longer while 48 hours of aerobic holding resulted in greater elevated and persistent metmyoglobin and a slow and incomplete conversion to reduced myoglobin.

Conont and Fieser (1924) and Neill and Hastings (1925) showed that oxidation of oxymyoglobin to metmyoglobin was encouraged by low partial pressures of oxygen. Oxidation

Table 12. Effect of Packaging Time on Visual Redness Scores of Frozen Beef Longissimus and Psoas Major Packaged in Skin-Tight Iolon Film

Display Day	Longissimus		Psoas Major	
	Package Freeze	Freeze Package	Package Freeze	Freeze Package
0	1.56 ^b	1.54 ^b	3.37 ^c	2.88 ^b
1	1.90 ^b	1.68 ^b	3.54 ^c	3.07 ^b
7	3.49 ^c	3.16 ^b	4.01 ^c	3.72 ^b
21	3.80 ^c	3.62 ^b	4.20 ^c	4.04 ^b
42	4.14 ^b	4.01 ^b	4.44 ^b	4.34 ^b

^a1 = very bright red, 2 = bright red, 3 = slightly dark red, 4 = very dark red, 5 = extremely dark red.

^{b,c}Means within muscle and day with same superscript letter are not different ($P > .05$).

was most complete at a partial pressure low enough to permit one half of the ferrous ions to be in the deoxygenated state. Brooks (1929) reported maximum conversion to metmyoglobin at a partial oxygen pressure of 4 mm.

George and Stratmann (1952) found that with pH, salt concentration and temperature held constant, the oxidation of reduced myoglobin to metmyoglobin was a first-order reaction where no protein denaturation occurred. They determined the maximum rate of oxidation of myoglobin to occur at partial oxygen pressures between 1 and 1.4 mm Hg but later showed that this maximum rate could be obtained at oxygen pressures up to 20 mm of Hg if the temperature and pH were altered. At oxygen pressures above 20 mm of Hg the oxidation rates leveled off to a constant value.

Dean and Ball (1958) advocated the marketing of red meat in vacuum packages, although they were concerned about the color darkening with a slow return to a brighter color.

Pierson *et al.* (1970) reported an initial formation of metmyoglobin with a subsequent reduction to reduced myoglobin for anaerobically packaged beef. The myoglobin formed at the surface of the meat within a few hours after packaging.

Figure 5 illustrates the relationship of partial oxygen pressure to the three chemical states of myoglobin. This figure helps explain the results of Dean and Ball (1958) and of Pierson *et al.* (1970). It also explains the brown metmyoglobin layer of fresh bright red steaks at some distance below the surface and explains the brown mottled appearance in frozen ground beef logs and even patties. Ground beef production can lead to uneven incorporation of oxygen into the ground product and "oxygen snarfing" activity within the muscle can produce localized areas of the low oxygen pressures which encourage metmyoglobin formation. Such mottling usually is dissipated when product is thawed and broken up.

A number of attempts have been made to market retail cuts in the reduced myoglobin (deoxymyoglobin) state, some reasonably successful. Marketing red meat in this purple-red condition requires consumer education and promotion. Recent studies (Anonymous, 1980) deal with marketing pork retail cuts in vacuum packages. Our research group at Kansas State University is currently studying display life on beef steaks in the deoxymyoglobin state, both fresh and frozen.

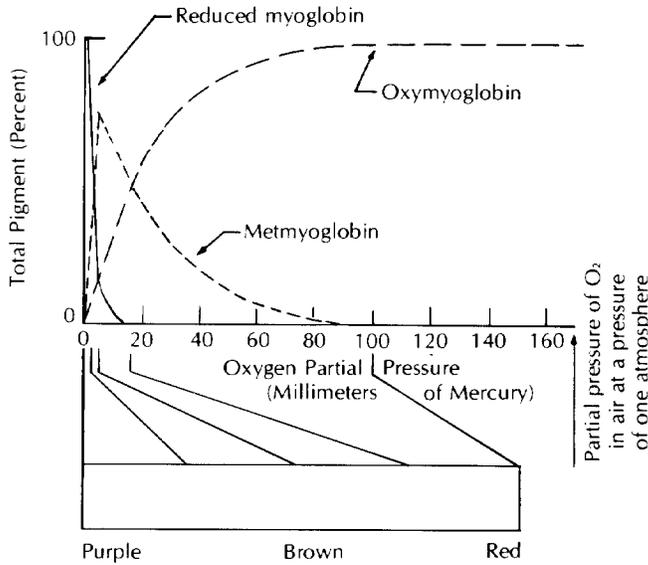


Figure 5. Relationship of Partial Oxygen Pressure to Myoglobin Chemical State.

Our fresh-vac beef muscles were satisfactory after 21 days of continuous display under 100 foot candles of Natural lighting @ $35 \pm 2^\circ\text{F}$. In pilot studies, ground beef samples maintained saleable appearance for 28 days and exhibited no "off aroma" or at the worst a very slight aroma when packages were opened. We have all noted the offering of beef and pork subprimal cuts in vacuum packages at retail outlets.

A worsening energy crunch may rearrange the USA meat distribution and marketing system. The longer shelf life with deoxymyoglobin cuts will be very helpful to central meat cutting operations such as Falley's headquartered in Topeka, Kansas. Currently, they deliver 5 days a week to their Manhattan store, but once or twice a week deliveries are definitely within reason for deoxymyoglobin cuts.

Retail cuts from vacuum packaged pork loins were higher in consumer acceptability and had less surface discoloration than those from pork loins wrapped in the traditional parchment paper or in 90 gauge polyvinylchloride film (with or without CO_2 pellets added) (Smith *et al.*, 1974). Loins were stored at 2°C for 5, 7 or 9 days, then displayed up to 3 days at 1°C under 82 to 100 foot candles of Incandescent lighting for 12 hours daily. Loins were satisfactorily stored for up to 28 days in vacuum packages and provided acceptable retail cuts, but results were not as favorable for Boston shoulders and their retail cuts. Retail packaging was not specified.

Some early relatively unsuccessful results with vacuum packaging for lamb cuts were largely due to high oxygen permeability of the bags used but vacuum bags with better oxygen barrier properties and improved film to meat contact are now produced. Varnadore (1972) reported lamb cuts to be satisfactory in appearance and quality after 21 days of vacuum storage and 3 days of display. Tatum *et al.* (1977) found chops from vacuum-packaged lamb loins to be quite similar in muscle color, surface discoloration and peripheral discoloration to those packaged in polyvinylchloride or naked with CO_2 pellets when stored for 7 or 14 days at 0° to 2°C and

displayed 1 or 4 days under 82 foot candles Incandescent lighting for 12 hours daily. Retail cuts were wrapped in an oxygen-permeable film (Goodyear Prime-wrap). However, for leg roasts, some improvement was noted in subcutaneous fat appearance and overall appearance for cuts from vacuum-wrapped lamb legs.

In studies on beef knuckle cut (round tip) vacuum packaging, Seideman *et al.* (1976) conclude that degree of vacuum had the greatest effect on fat appearance score, proportion of surface discoloration score and total desirability score of primal cuts, but did not affect % purge loss even though this cut is a "bleeder cut." After 7, 14, 21, 28 and 35 days of storage for the beef knuckles, retail cuts were packaged in polyvinylchloride and displayed at 1° to 3°C under 90 foot candles of incandescent lighting for up to 4 days. Low, intermediate or high vacuum had no large effect on retail steak scores for proportion of surface discoloration, peripheral discoloration and total desirability (of appearance). Harrison *et al.* (1979) compared subjective and objective color measurements of beef steaks from 4 beef muscles, cut after a 48 hour carcass chill or cut after an added 21 days of vacuum storage. Longissimus, biceps femoris and semimembranosus steaks from those muscles stored in vacuum 21 days remained brighter through 3 days of display than those cut into steaks after a 48 hour chill. Vacuum storage prolonged visual acceptability of biceps femoris and semimembranosus steaks an extra day. However, steaks from vacuum packaged muscles were darker after 5 days of display. Percent metmyoglobin showed similar trends but darker color was associated with higher metmyoglobin. Semitendinosus did not respond in the same manner as the other muscles.

Seideman *et al.* (1980) prepared "re-formed subprimals" by cutting beef, pork and lamb loins into steaks or chops, re-forming the wholesale cut by holding cuts together and vacuum packaging them. This system gave good results when compared to vacuum packaged primals, after storage of 7, 14 or 21 days and display of 1, 3 or 5 days for beef, pork and lamb.

Modified Atmosphere

An extensive and excellent review was given on this subject by Gail Holland (1980). An Outstanding Symposia in Food Science and Technology entitled "Extending the Shelf Life of Fresh Foods by Combining Controlled Atmospheres and Refrigeration" is available in the March 1980 Food Technology.

Gases used to modify in-package atmospheres have included nitrogen, carbon dioxide, carbon monoxide and oxygen or combinations. A hypobaric oxygen environment, such as that which occurs in a vacuum package can also be considered a modified, or controlled atmosphere.

My discussion will focus on effects of modified atmosphere on color and not on microbial effects.

Nitrogen gas is commonly used for gas flush packages of cured meat products, such as wafer sliced products. Partmann *et al.* (1970a,b) stored meat 7 days in metal boxes with a slow continuous flow of 100% N_2 and found good surface color appearance for beef, pork and calf carcasses maintained at 7°C and for carcass parts at 3°C . Setser *et al.* (1973) noted a

trend toward more rapid discoloration for beef semitendinosus samples kept in 100% N₂ (0% O₂) than samples kept in air or 100% O₂ with temperature at 4.5°C and exposed to 405 or 577 nm monochromatic light. Huffman *et al.* (1975) found 100% N₂ not effective against aerobes, but color of beef longissimus was similar to that maintained in 100% CO₂ in the dark at 1°C. Seideman *et al.* (1979c) indicate that 100% N₂ serves no useful purpose except to minimize weight losses. However, samples stored in 100% N₂ versus vacuum packed cuts for 7, 14, 21 or 28 days were not different in reduced-, oxy- or met-myoglobin after 5 hours or 3 days under display conditions and were not different in steak surface discoloration after 3 days display (in polyvinylchloride film at 1°C under 970 lux of incandescent light). Nitrogen may increase "off-odor" and decrease attractiveness of subcutaneous fat (Anonymous, 1979).

Regarding use of high carbon dioxide (CO₂) levels, Ledward (1970) reported an increased CO₂ absorption on the meat surface at high CO₂ partial pressures resulting in a reduced muscle surface pH. Partmann *et al.* (1970a,b) found 70% CO₂-30% air to be effective in microbial control but this treatment for 7 days caused a grey or brownish discoloration at 3°C and an "unpleasant" color at 7°C in beef, pork and veal. Huffman *et al.* (1975) found 100% CO₂ to lower aerobic counts and 630 nm reflectance was similar to that of 100% N₂. Ordonez and Ledward (1977) found metmyoglobin formation at the muscle surface to be independent of CO₂ level when comparing 10 and 20% CO₂. A report in *Meat Processing* (Anonymous, 1979) reports CO₂ to be more effective in microbial control with increasing concentrations, but over 25% CO₂ causes a brown meat surface color. Seideman *et al.* (1979c) used beef longissimus stored for 7, 14, 21 and 28 days in 100% CO₂ and found that steaks displayed for 5 hours were not different in degree of surface discoloration than steaks from vacuum packaged cuts stored a similar time. However, steaks from loin strips stored 21 or 28 days in 100% CO₂ were more discolored and had a lower percent of oxymyoglobin after a 3 day display than similar steaks stored in vacuum. However, no difference was found in % metmyoglobin after 3 days of display.

Wolfe (1980) states that for fresh meat, fish and poultry, rapid attainment of low temperatures can retard most deterioration except spoilage by psychrophilic organisms and CO₂ is effective against these, even with elevated O₂. The principal disadvantages of use of high CO₂ atmospheres in fresh meat storage are color darkening due to metmyoglobin formation and continuation of fat oxidation. These occur very effectively even at low O₂ concentrations. However, carbon monoxide has the potential to retard these processes.

Some studies have dealt with elevated levels of oxygen within the meat package. Huffman *et al.* (1975) stored beef longissimus in 100% O₂ in the dark at 1°C and reported a higher reflectance at 630 nm (indicator of a brighter color) for up to 20 days than for samples exposed to air. However, this 630 nm reflectance was not as high as for samples stored in 100% N₂, 100% CO₂ or in a mixture of 70% N₂, 25% CO₂ and 5% O₂. MacDougall and Taylor (1975) found increasing oxygen concentration in a controlled atmosphere package to result in a thicker surface layer of oxymyoglobin which masks the brown metmyoglobin up to the limiting depth of oxygen

penetration. The oxymyoglobin layer becomes thinner with display time. In a commercial scale trial, 97% O₂ was measured in the polyethylene bags after the oxygen flush and over 90% still remained after transportation and storage. Psoas major and gluteus medius from 2 week aged carcasses remained bright longer at 4° and 7°C when stored in oxygen rather than air. However, the longissimus shelf life was not lengthened by oxygen storage. The report in *Meat Industry* (Anonymous, 1979) indicated that color and odor shelf life were improved with increasing oxygen, up to 50% O₂. Seideman *et al.* (1979c) stored beef longissimus in 100% O₂ for 7, 14, 21 and 28 days and found no difference in retail packaged beef longissimus degree of discoloration than for cuts from vacuum stored beef. Oxymyoglobin percentage was lower in longissimus displayed 3 days when it was derived from muscle stored in 100% O₂ for 7 or 14 days compared to that from cuts vacuum stored at similar time. Seideman (1979b) found that steaks displayed 1 or 4 days had more surface discoloration when cut from longissimus muscle stored in 100% O₂ for 7, 14, 21 and 28 days than from those vacuum stored a similar length of time.

Oxygen and carbon dioxide mixtures offer some good possibilities. Ledward (1970) found carbon dioxide above 10% to have a negligible effect on increasing metmyoglobin provided that oxygen level was at 5% or higher. Taylor and MacDougall (1975) found beef semimembranosus packaged in 80% O₂ and 20% CO₂ remained attractive for 1 week at 1°C. Since the study dealt primarily with gas exchanges, samples were packed in sealed metal cans. The 80% O₂ resulted in a thicker oxymyoglobin layer than a 60 or 40% level.

Ordonez and Ledward (1975) found higher oxygen to result in lower metmyoglobin formation. For pork longissimus and biceps femoris exposed to 80% O₂ and 20% CO₂, metmyoglobin was still below 30% after 15 days storage. Silliker *et al.* (1977) exposed beef round steak to combinations of 5 to 30% CO₂ and 25 to 65% O₂ and found color after storage to be improved by increasing oxygen and best with 10% CO₂ and 65% O₂. Less than 50% O₂ resulted in brown discoloration.

Seideman *et al.* (1979b) found beef longissimus exposed to higher oxygen levels to have higher surface discoloration scores, shorter shelf life and more metmyoglobin than those stored in vacuum or 20% CO₂ and 80% N₂.

Lopez-Lorenzo *et al.* (1980) used ground pork and found that increasing oxygen to 80 to 100% O₂ reduced myoglobin oxidation. These high oxygen levels increased the time from 4 days for controls to 13 days for occurrence of 50% metmyoglobin. Lipid oxidation was reduced by 20% CO₂.

Carbon dioxide and nitrogen mixtures have received considerable attention. The most frequently used 20% CO₂-80% N₂ mixture was tested by Partmann *et al.* (1975) for beef longissimus samples of defined volume and surface area @ 1°C. Those stored in a still atmosphere had excellent color and visual freshness after 6 weeks of storage while a flowing 20-80 atmosphere resulted in poorer color, possibly due to traces of oxygen. Seideman *et al.* (1979b) found the 20-80 gas atmosphere generally equal to vacuum for beef muscle after storage or 1 or 4 days of display.

Seideman *et al.* (1980) found the 20-80 to result in more discoloration than vacuum retail cuts of beef longissimus, but a 40-60 gas mix resulted in equal appearance to vacuum after

5 days of display. For pork chops, the 20-80 was equal to vacuum storage except for long storage (14 or 21 days) and long display (5 days). Lamb chops responded equally, except that long-stored cuts from the 20-80 were darker than vacuum stored after 1 day of display, but not 3 or 5 days. Hall *et al.* (1980) stored pork loins in vacuum, 20-80 or 40-60 CO₂ to N₂ and found them similar in visual color, odor, fat appearance and muscle discoloration after varying storage up to 28 days and similar in degree of surface discoloration after 5 days display.

Partmann *et al.* (1970a,b) found 1% O₂ and 99% N₂ to not have a very satisfactory effect on appearance of beef, pork and veal parts stored at 3°C for 7 days. Carcasses exposed to 1 or 3% O₂ in nitrogen at 7°C for 7 days were not satisfactory, either.

A more recent trend is to explore more complex gas mixtures. Taylor and MacDougall (1975) replaced part of the nitrogen in the 20% CO₂-80% N₂ mixture with 40 or 60% O₂ and found improved color hue and saturation (calculated from Gardner readings) as compared to control beef semimembranosus stored in air.

Partmann *et al.* (1975) found less satisfactory results for beef longissimus held at 1°C if the nitrogen in the 20:80 mix was partly replaced by 10 or 50% O₂. Huffman *et al.* (1975) noted a similar beef longissimus 630 nm reflectance for samples stored in 70% N₂-25% CO₂-5% O₂ as for those stored in 100% CO₂ or N₂.

Seideman *et al.* (1979b) tested storage of beef longissimus in 25% CO₂-25% O₂-50% N₂ and noted more discoloration than for primals stored in vacuum. A higher metmyoglobin percentage was noted after 14 and 21 days of storage. Retail appearance of steak from those primals was not satisfactory after 4 days of display but that was also noted for steaks from vacuum packaged primals. Use of a modified atmosphere gas mixture of 51% CO₂-30% O₂-18% N₂-1% CO resulted in less metmyoglobin than for vacuum packaged primals after 35 days of storage. After 4 days of retail display of steaks from these primals compared to vacuum stored primals (storage of 7 or 21 days), less discoloration was noted.

In 1964, El-Badawi *et al.* found a mixture of 2% carbon monoxide and 98% air used to flush the package prior to sealing to be very effective in stabilizing the color of fresh beef for 15 days. Product was displayed at 36° to 38°F (2.2° to 3.3°C) under fluorescent lighting (unspecified) at 125 foot candles. Saran-mylar-polyethylene or 2.5 mil polyethylene pouches were more effective than 1.5 mil polyethylene pouches.

Clark *et al.* (1976) compared in-package environments of 100% air, 100% nitrogen and 0.1, 0.5, 1.0, 5.0 and 10.0% carbon monoxide (CO) with the balance nitrogen and found CO levels of 0.5% or higher to increase color and odor shelf life to 30 days compared to 5 days for controls in air. Lean rump muscle was wrapped in polyvinylchloride, then overpackaged with saran barrier bags and incubated at 0°, 5° and 10°C in the dark. A few samples were exposed to 99% CO gas for 2 to 16 hours and then packaged in polyvinylchloride film and incubated in air with no saran overwrap. These samples did not have greater shelf than untreated samples in air. Other muscle samples removed from the CO containing barrier bags had a shelf life after that time like those untreated and kept in air.

Gee and Brown (1978a) stored ground beef in a 1% CO atmosphere at 2°C for 3.4 days, then held it in air at 1.7°C under fluorescent illumination (15 Watt at 50 cm). After the CO exposure, 17% of myoglobin was carboxymyoglobin, but in air this pigment decreased with an estimated half life of 2.1 days. Treatment of ground beef samples with 1% CO, 50% CO₂ and 49% air maintained a fresh red color for 6 days compared to 3 days for air stored samples (Gee and Brown, 1978b).

Lanier *et al.* (1978) reported for ground beef at pH 5.6 that CO at 1 or 5% in air accelerated metmyoglobin reduction, even in the presence of air. Seideman *et al.* (1979a) investigated a variety of gas atmospheres for boneless pork loin roasts, including one with 1% CO, 51% CO₂, 30% O₂ and 18% N₂. Cuts were sealed in laminated nylon/saran/polyethylene pouches, gas mixtures were injected through a layer of dried silicone glue, then stored for 7, 14, 21, 28 or 35 days. Half of each roast was displayed in polyvinylchloride film at 1° to 3°C under 970 lux of incandescent light. After storage, appearance did not differ from that of vacuum-packaged roasts, but cuts displayed 3 days were more extensively discolored than those obtained from the vacuum stored roasts.

Lentz (1979) exposed beef samples to 100% CO for 3 hours prior to packaging beef biceps femoris and semimembranosus in a highly oxygen permeable film, vacuum packaging and freezing in an air blast freezer at -29°C. He noted a bright red appearance with greatly improved color shelf life.

Wolfe (1980) states that CO has the potential to retard metmyoglobin formation and fat oxidation, but CO has not been approved by regulatory agencies for commercial use with meat.

The possibility of carbon monoxide toxicity is dealt with by Tappel *et al.* (1954) who calculated a hemoglobin saturation of 0.7% by carbon monoxide, compared to a 10% saturation needed to show detrimental, but temporary effects. Clark *et al.* (1976) calculated a very low exposure of the body to CO from consuming CO treated meat. Watts (1978) used a ¹⁴C isotope labeling study to show that less than 0.09 ppm of CO remained in cooked ground round that had been exposed to CO.

However, the regulatory agencies may be more concerned about misrepresentation of the condition of meat products and the possible masking of the microbial condition by the bright red carboxymyoglobin. A combination of CO with other gases, such as CO₂, which control microbial growth, should have better prospects for approval.

Modified atmosphere packages with gas in the package take more shipping space and more box for a given meat tonnage than for vacuum packaged cuts. This may be a very important consideration, especially with shipping space limits.

Summary

In studies involving display, the following factors could have a bearing on outcomes. We would be more enlightened if as many as possible of these conditions were specified.

Display lighting

Specific name of lamp

Wattage of lamp and distance from samples
 Lighting intensity at meat surface level
 Hours per day of lighting
 Length of display study

Display Temperature

Air inlet
 Meat surface level (front and rear)
 In muscle, just below surface
 Defrost cycle information

Gas Environment

Film gas permeability (at temperature of display, if possible)
 Bloom time or prepackaging gas treatment
 Extent of vacuum
 Shrink of film
 Atmosphere modification
 Freeze-packaging sequence
 Time from packaging to freezing, if packaged first
 Freeze temperature cycle

Muscle or Meat Sample

Specie
 Specific muscle
 Location within muscle
 Red area vs. white area
 Ageing time
 Previous temperature and handling
 Bloom and time
 Reduction of myoglobin and time

Discussion

K. R. Franklin, National Live Stock and Meat Board: Don, in your series of photographs that you showed us displaying the different light sources, can you tell us first what film was used to take the photographs, and was there any attempt made to standardize the film emulsion?

D. H. Kropf: The first one I can't answer. I can find it out, I think. For the cured wafer sliced product, I had a slide in there of how it looked at 3400 degrees Kelvin which would be a standard condition for a photographer. Yes, an effort was made to standardize the emulsion. I think they were very careful, Ken, to do that in those slides.

K. R. Franklin: I think it would be helpful if we could know what the film was. Whether it was 3200° Kelvin or whether it was daylight. We've tried to do a lot in this regard and we find that there is really no completely satisfactory film to record the effects of fluorescent lighting without a lot of filtration.

D. H. Kropf: I think your point is well taken. We've looked at this and the product appearance. We thought it was a quite faithful rendition according to our subjective judgement.

T. R. Dutson, Texas A&M University: We've found that using a color standard and taking some of these kinds of pictures gives fairly good pictures on all Kodak film. I think Ken has used the standard. There are some various color standards that have the different colors in there and so in the reproduction of the film this color standard can be matched back to what the color standard is right in the darkroom. I think that

way you can get the actual color that was there at the time, because it kind of eliminates some of this problem in balancing.

D. H. Kropf: Yes, and I would say, to a degree, our photographers did this thing. It's a good point.

L. J. Ernst, American Can Company: Dr. Kropf, can you give any explanation or comparison of the nafa lighting that's used in European supermarkets. They are both pink and/or heavily oriented toward the red. Is there any information available on the actual wavelengths or amount of red in either, or in the comparison?

D. H. Kropf: I haven't seen this data. I would say, Lyle, that probably I don't get enough European literature. We are contemplating some additional studies under light sources. We haven't done it for awhile. I would be interested in any unusual lamps that you would have for us to use.

L. J. Ernst: I don't know if Dr. Galloway has obtained lamps yet, but we are in the process of obtaining some and we would be willing to supply you with whatever literature they have available. We attempted to do this for the past two years and their supplier in the U.S. has changed several times in that period. Also, to comment on this photography aspect in the previous question. We see in the work that we do in our laboratory, our internal photographer used one type of film under one set of conditions and then we hire a local, outside photographer and he gets the same results using a different type of film. Also, taking photographs in the display cases or with a specific background gives you an entirely different set of conditions. For instance, with a white or light blue or black background vs. a typical display case, you have to change the film and all the conditions completely.

D. H. Kropf: We recognize that and agree with you. I might say we've talked to the Sylvania people more than others and they recommend that we look at Royal Light and also there are some halogen luminars now that I'm much interested in studying.

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