Lighting Systems for Fruit and Vegetable Sorting
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Lighting Systems for Fruit and Vegetable Sorting

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Fruits and vegetables are inspected prior to most packing or processing operations. The purpose of inspection is to sort out (discard) the individual items that have characteristics undesirable for fresh market sale or for processing. Most sorting is done by human visual inspection. Workers perform the manual sorting operation as the fruits or vegetables move past them rapidly on roller or belt conveyors. Each worker typically must look at a few hundred items each minute, and accurately discard those that are unacceptable. Good lighting conditions are necessary for good sorting efficiency.

"Light" is a very general term and, in most applications, is taken for granted. Lighting, however, may not match well with the specific task for which it is intended. Specific guidelines for lighting system design in fruit and vegetable sorting and packing lines in the United States do not exist. Manufacturers of packing line equipment have left lighting decisions up to the individual operation. Improper selection of equipment results in lighting that is inadequate for conducting the inspection.

Agricultural products can cover the entire spectrum of visible colors. A given product is usually within a well defined color range, but color variation on and between items can be high. Defects can occur anywhere on the fruit or vegetable, be of any size, and occur in a variety of colors. Light provided for inspection must have BOTH adequate intensity and adequate color quality to enhance or reveal these defects, rather than obscure or mask them.

Improper lighting design promotes worker fatigue and eye strain, and results in poor sorting efficiency. Studies of several operations involving inspection of a range of fruit and vegetable commodities have shown that many lighting systems are not adequate for the required task. These studies suggest that sorting could be improved if inexpensive changes in illumination sources, illumination intensities and background colors were adopted in sorting areas.

Principles of Lighting and Color

Two common uses of lighting are general area lighting and task lighting. General area lighting illuminates a room or building and is usually mounted in the ceiling or well above the floor area. Task lighting is much more specific and is concentrated in an area to enhance the ability to perform a task. Task lighting is the primary concern of this publication which focuses on the task of manual sorting of fruits and vegetables.

Color is an important part of task lighting for manual sorting. Three major components interact in the process of visualizing a "color" (see Figure 1):

A) spectral irradiance or light energy from a lamp or lighting fixture (source)
B) color spectral reflection or light reflection of the item
C) spectral receptor or sensitivity of the eye to light or color

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For example, to "see" the color red requires a light source containing red color light, a surface which can reflect the red light, and a receptor which is sensitive to the reflected red light.

The term "color" is used loosely here, as the basics of color are beyond the scope of our discussion and would take considerable space to accurately and clearly define.

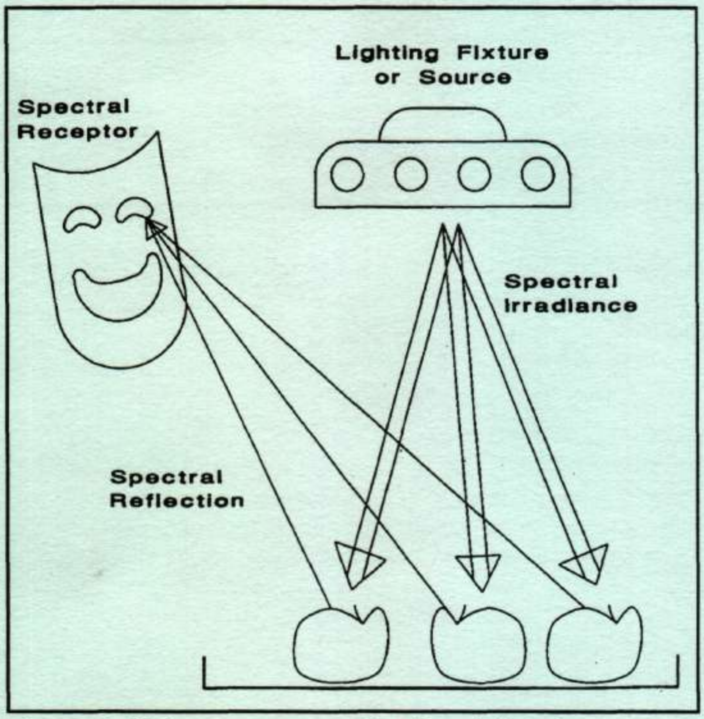

Figure 1. Major components in visualizing the color of an object.

A) **Spectral Irradiance or Light Energy**

Light energy, or a source of light, is required to produce the actual visible colors which are reflected for the eye to detect. The natural light source is the sun, which produces all visible colors in addition to energy outside of the visible spectrum (ultraviolet, infrared, etc.). Colors produced by artificial light are influenced by tube coatings, such as phosphors in fluorescent tubes or gases or other components contained in filament bulbs.

Artificial light sources are rated by the following:

- Color temperature; black body temperature generation in degrees Kelvin
- CRI: Color Rendering Index; effect that the light source has on appearance of colored objects, 100 = perfect appearance.
- CPI: Color Preference Index; how well people recognize colors in that light, 100 = perfect recognition.

Of the three major components in visualizing color, light energy is most easily controlled. The important factor relating to artificial light is the spectral irradiance curve for a given light source. A spectral irradiance curve measures the amount of light energy at each wavelength contained in the source over the spectrum of colors (Figures 2a and 2b). This is important because overall color is based on the combined levels of energy produced at each wavelength of the color spectrum. Spectral irradiance curves are generally available from lamp manufacturers. The spectral irradiance for a light source can be altered with various types of filters covering the lamp. This includes undesirable coatings such as dust and dirt. The specific science relating to how the irradiance is developed will not be discussed, other than to note that light sources can be compared on the basis of colors produced (similarity or difference of their spectral irradiance curves).

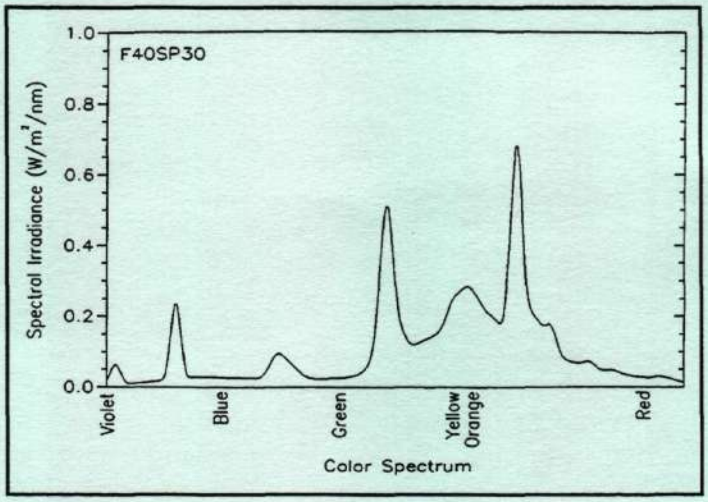

Figure 2(a)

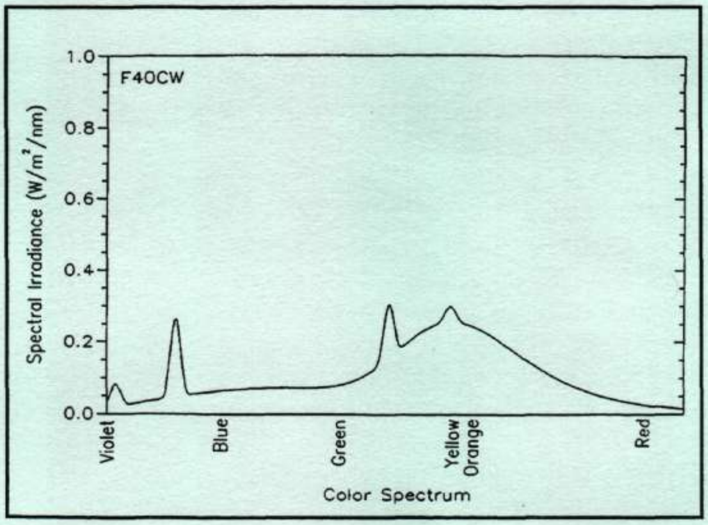

Figure 2(b)
Spectral irradiance curves from; (a) SP-30 and (b) Cool White illumination sources (Brown et al., 1993).

B) Spectral Reflectance

Spectral reflectance is the relative amount of light energy at each wavelength reflected by an object. By combining the reflected energy from the various wavelengths, the human eye determines the "color" of the object. The "color" generally means the ability of an item to reflect certain colors in the presence of natural light. In fruits and vegetables it is the chlorophyll, anthocyanin or other natural pigments that dictate the item's apparent color. Changing the light source or the sensitivity of the spectral receptor alters the apparent color of an item. Figure 3 gives examples of measured spectral reflectance curves for green peppers, golden Delicious apples, and dark sweet cherries. Note how measurements of some defective and nondefective areas for the same commodity vary in their reflectance over the entire spectrum, while others vary only in certain regions of the spectrum or they vary little at all.

Many defects that need to be detected on fruits and vegetables are of brown or grayish color. One might assume that finding the light source with the most energy in the brown color regions would be ideal for all applications. However, the objective in selecting the best light source for a given task is to accentuate the color **difference** between the defects and the normal tissue of the commodity. For example, to find green-end on potato tubers, use light of a color that will accentuate green against the normal light brown of potato tuber skin. The key is to find a source of inspection lighting that will show the defects most clearly, but still makes the commodity look realistic.

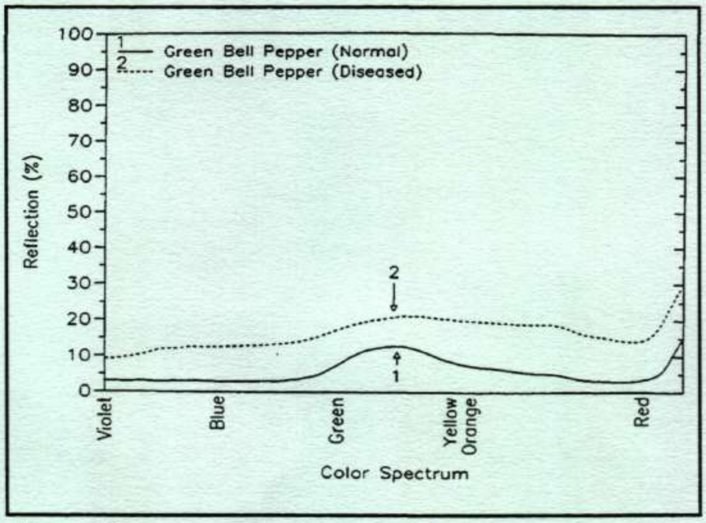

Figure 3(a)

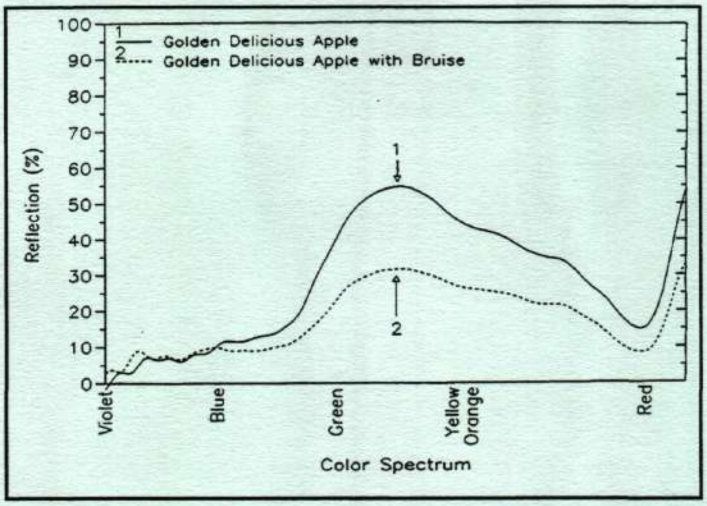

Figure 3(b)

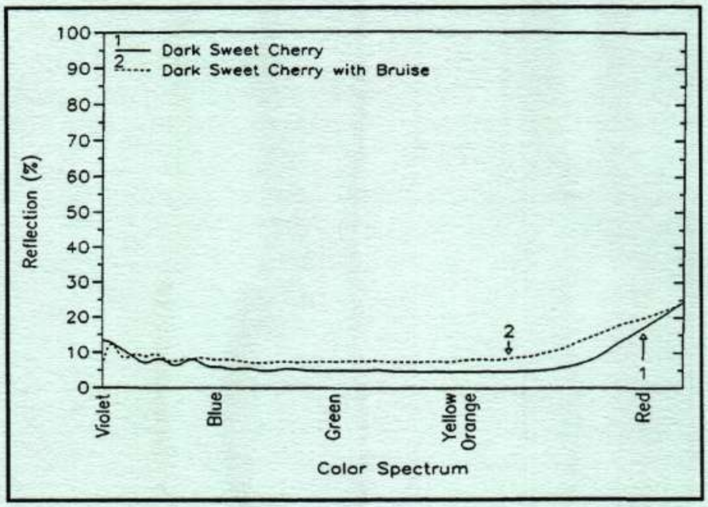

Figure 3(c)

Spectral reflectance curves for normal and defective tissue of (a) green bell pepper; (b) golden Delicious apple; and (c) dark sweet cherry (Brown et al., 1993)

C) Spectral Receptor (Eye Sensitivity)

The third component in perceiving a color is the receiving or sensing of the light. The focus of our discussion is on manual sorting and we therefore consider the human eye as our receptor. No adjustment to the human eye exists. The only variability is in the individual's sensitivity to the color and quantity of the light. Figure 4 shows a typical visible wavelength response curve for the human eye. Sensitivity will decrease with age, so this must be a consideration during lighting design.

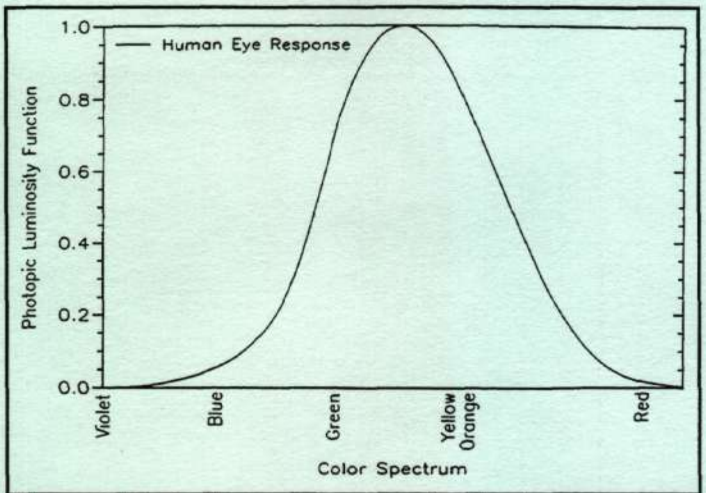

Figure 4. Typical response curve for the human eye (Kantowitz and Sorkin, 1983)

Perceived Color

Figure 5 demonstrates the combining of all three components (using Figure 2a spectral irradiance and Figure 3c reflectance curves and Figure 4 receptor sensitivity) which affect color perception. The perceived color is termed the total spectral energy distribution and is the product of the spectral irradiance times spectral reflectance times human eye sensitivity or response.

The ideal distribution or goal of the lighting design is to have "peaks" in the spectral distribution at the wavelengths or colors of the commodity and at the defect color, resulting in a good perceivable contrast. For example, if the need existed to identify brown defects on the surface of a red commodity, a light source with high levels of energy output in the colors which make up brown (all colors) and red would be necessary to enhance both colors for easier discernment.

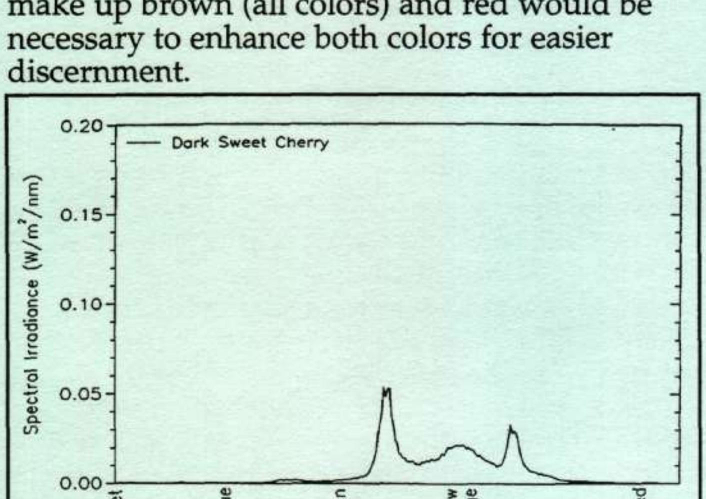

Figure 5. Perceived color based on Figures 2a, 3c and 4 (Brown et al., 1993)

Performance of Commercially Available Light Sources

Theoretically the product of the spectral irradiance, spectral reflectance, and eye sensitivity should provide the information to design a proper lighting scheme. USDA-ARS researchers at Michigan State University evaluated several commercially available light sources. They measured individual spectral irradiance and used color chips to subjectively analyze and compare performance in color perception tests. Table 1 summarizes the findings of these measurements and tests and provides some technical and relative cost information. Results indicated the 'image' curves resulting from the combination of spectral reflectance times spectral power times eye sensitivity generally agree with the subjective/visual results for the test with the color chips and real produce items.

The decreased ability to recognize the difference between good and defective areas on produce under Cool White (CW) light was also apparent for CW Deluxe, Warm White (WW), Warm White Deluxe, Daylight, Natural, Optima 32, Optima 50, C-50, and C-75 fluorescent lighting. Consequently, these lights should not be used for task lighting in fruit and vegetable inspection areas.

Visual color comparisons suggested that, although the SP-30 light had a low color-rendering index (CRI), it performed better than higher CRI fluorescent lights for the visual sorting of most fruits and vegetables. The relative light output of the SP-30 lamp is among the highest tested. Its cost is only 1.8 times that of CW. These factors indicate that it should be an appropriate choice for most sorting operations when both sorting performance and lighting cost are considered.

Except for metal halide, the high intensity discharge (HID) lights were undesirable for produce sorting as they severely darkened most colors. Tests using metal halide light will be necessary to determine if sorting performance is acceptable. Tungsten halogen (quartz) light provides good color recognition and enhanced ability to see brown colored defects on dark colored produce. Both metal halide and quartz lighting will be more costly than SP-30 fluorescent lighting. More specific discussion of the tests can be found in the cited references.

Table 1. Artificial lighting characteristics and visual effects on common produce colors, 1992*

Light Source	Mfgr	Rel cost	Color temp	CRI	CPI	Rel light	Visual effect on specified color: Maroon	Red	Green	Brown	Blue	Purple	Yellow
Fluorescent Tubes													
SP-30	1	1.8	3000	70	80	105	E	E	B	E	D	E	E
SPX-30	1	5.9	3000	82	100	105	E	E	B	E	D	E	E
ULTRALUME-30	2	3.7	3000	85	100	105	E	E	B	E	D	E	E
WARM WHITE	2	1.3	3000	53	37	102	E	E	D	E	D	D	E
WARM WHITE DELUXE	2	2.1	3000	79	90	68	E	E	D	E	D	E	E
OPTIMA-32	3	4.9	3200	82	-	81	E	E	B	E	D	E	E
NATURAL	2	3.1	3400	81	93	66	E	E	E	D	E	E	W
COOL WHITE	2	1.0	4100	67	58	100	D	D	E	W	E	D	W
SPX-41	1	6.5	4100	82	100	103	E	E	E	W	E	E	W
COOL WHITE DELUXE	2	3.2	4200	89	94	70	E	E	D	D	E	E	D
COLORTONE-50	1	3.2	5000	90	92	70	E	E	E	W	E	E	W
ULTRALUME-50	2	4.1	5000	85	100	105	E	E	E	W	E	E	W
OPTIMA-50	3	5.2	5000	91	-	81	E	E	E	W	E	E	W
VITA-LITE PLUS	3	5.7	5500	91	-	100	E	E	E	W	W	E	D
DAYLIGHT	2	1.7	6500	79	72	83	D	D	E	W	E	D	W
COLORTONE-75	1	4.2	7500	95	97	64	E	E	E	W	E	E	W
HID and Incandescent Bulbs													
LOW PRES SODIUM†	2	-	1800	0	0	200	D	D	D	D	D	D	D
HIGH PRES SODIUM	2	17.0	2100	50	-	150	D	D	D	D	D	D	D
TUNGSTEN HALOGEN	2	6.4	2900	100	100	30	E	E	B	E	W	E	B
METAL HALIDE	2	17.7	3200	70	-	130	E	E	D	E	D	E	D
COLOR COR MERC VAP	2	16.0	3800	60	-	80	W	W	E	W	E	W	W
MERCURY VAPOR	2	12.4	5400	20	-	65	D	D	W	W	D	D	W

* Mfgr: 1 = General Electric; 2 - Phillips; 3 = Duro Test.

Rel Cost: Relative bulb cost ratio to Cool White.

Color Temp: Lamp appearance in degrees Kelvin.

CRI: Color Rendering Index = effect the light source has on appearance of colored objects, 100 = perfect appearance.

CPI: Color Preference Index = how well people recognize colors in that light, 100 = perfect recognition.

Rel light: Relative initial lumen/watt output as a percentage of Cool White.

Visual effect of tube on specified color: B = Brownish cast; D = Darker; E = Enhanced; W = Whitish cast. Cool White effects are relative to midday diffuse outdoor light, other tubes are relative to Cool White.

† Colors were darkened so much that recognition was extremely difficult.

Light Source Availability, Adaptability and Federal Regulations

In an effort to conserve the nation's energy resources, the Federal Government, as of 1994, prohibits the manufacturing of many common wattage fluorescent and directional incandescent lamps for sale in the United States. Certain eight-foot fluorescent types, including the popular CW and WW lamps, are out of production (except for Watt-Miser styles), and many common four-foot fluorescent lamps will be obsolete by October 1995. As soon as inventories of existing lamps are depleted, facilities will have to substitute with approved lamps. The SP-30 lamps, or equivalent, are suitable substitutions that meet the new federal standards and can improve fruit and vegetable sorting.

In anticipation of the loss of the CW and WW lamps, packers and processors should be planning now to improve lighting. Recent technological breakthroughs in lighting can offer substantial benefits while bringing lighting up to the federal standards. The new standards should be looked upon positively as a catalyst in reducing overall lighting costs while improving the light type and levels for safety and productivity.

In planning modifications of existing lighting systems or in designing new systems, several compatibility factors should be considered.

- T-12 (1.5 inch diameter) type fluorescent lamps can be replaced with more efficient lamps of equal length like the SP-30, with no changes to the fixture or ballast.
- Newer style T-8 (1.0 inch diameter) lamps will fit in T-12 fixtures, **However**, the ballasts must be changed. Electronic ballasts provide the highest efficiency.
- New installations could incorporate the more energy-efficient T-8 series of fixtures and lamps.
- All installations should have a regular maintenance schedule to keep fixtures and lamps clean and free of dust. Dirty lamps and fixtures decrease the lighting efficiency and quality of the light.
- A lighting representative or distributor can help select the optimal type of lamp for sorting requirements and ensure that all components of the lighting system are compatible.

Requirements of Light "Quantity"

The average illumination intensity needed on produce items for effective visual sorting is in the range of 250 to 500 foot-candles, based on the reactions of workers 20 to 70 years old. The lower intensity seems adequate for light-colored (high reflectance) produce and the higher intensity for dark-colored (low reflectance) produce. The actual light intensity may need to be adjusted, depending on the adaptation of the design considerations discussed below. The amount of light falling upon a surface can be measured with commercially available light (foot-candle) meters.

Eye sensitivity to light is known to decrease with workers' age. Consequently, sorters about 50 years old and older should work under about twice the intensity of light needed by sorters in their 20s.

When varieties of produce covering the entire color range must be inspected on the same packing line, the low and high intensity levels should be selectable by the sorting workers. This can easily be accomplished by using four-tube fluorescent fixtures wired so that either the two outside tubes or all four tubes can be turned on.

Considerations in Design

Several physical design characteristics will impact sorting efficiency and overall worker performance (see Figure 6):

- *Background color of sorting surface* (belt). Reflected light energy from the sorting surface should not be greater than reflected light from the produce. Use belts that are black or dark gray, brown or green, but not glossy in finish.
- *Surrounding colors.* Surfaces near sorting areas and the clothing of inspection personnel should not be bright or highly reflective, and should not cause glare.

- *Placement of fixtures*. The light source should not shine directly in the sorters' eyes, i.e., unshielded, or too low so as to obstruct the view of the sorting surface. The fixture must also be placed at a height that provides the proper amount of light at the sorting surface. This will depend on the amount and type of light utilized and the considerations mentioned above. Fixture height will also vary, depending on whether standard or high output lamps are used. For a standard output SP-30 light, this height will be about 22 to 32 inches above the sorting surface when the 4-tube fixture is centered over a 12- to 30- inch-wide belt. Wider belts may require more fixtures to be positioned perpendicular to the belt travel and above head height.

- *Type of lighting*. Light type should be appropriate for the sorting task and the colors involved. The quality and quantity of area lighting should also be considered, as it can have negative impacts on the color evaluation and on eye strain.

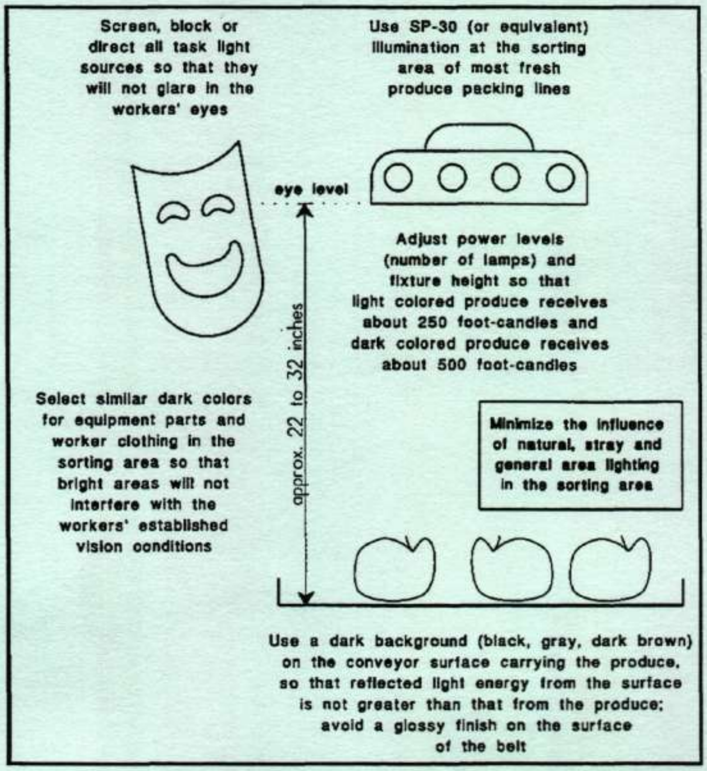

Figure 6. Primary design and management criteria for lighting at sorting areas.

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