Tone variations on the lunar maria are not related to recognizable topography. This is readily apparent in Figure 8, where isotonal lines of the darker mare material not obscured by rays, cross the low mare ridges indiscriminately. This relationship suggests that these tone variations were present before the formation of the maria ridges. These variations are most likely the result of textural and compositional differences, and may be related to the age and genesis of the material. Although conclusive evidence is not available as to the exact nature of this material, a popular theory suggests an extrusive origin. The tone variations observed on the mare surfaces are not dissimilar to tone differences observed on terrestrial flows of basalt or welded tuff (Smith, 1960 and van Bandat, 1962, p. 57).

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*A Freon-Cooled Film Viewer**

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ABSTRACT: *NRI is developing a system to solve a particular film analysis problem where large quantities of photographic records must be viewed and measured. The film is in reels of several widths, up to 9½ inches, and in lengths up to 1,000 feet. Much of the imagery is very dark with a high average density. In order to identify the picture detail the operator must see the projected picture with an average luminance suitable for the best operating range of the human eye. Therefore the energy of visible light incident on the dark field must be many times greater than the necessary transmitted energy for the projected picture. This calls for a very high intensity light source.*

In order to prevent film damage, a large amount of heat must be removed from the system. A technique used in printing photographs has been adapted for this application. The film which is in the illuminated platen area passes between two glass plates and is surrounded on either side by flowing Freon. The liquid used is Freon 113 which is a liquid at room temperature, has a high enough specific heat to carry off the absorbed energy from the film, and has an index of refraction very close to that of film.

THE instrument described in this paper is a rear-projection viewer which permits high intensity illumination and projection of a wide variety of films. It was developed in response to a photointerpretation problem—that of viewing many different kinds of imagery and sizes of film with enough intensity control to present the image at the optimum viewing condition, without damaging film. The major problem is keeping the film cool while passing high intensity light through it. The photographs that are under study may vary in density from almost clear film to an average density of 3 over the viewing region.

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Viewing conditions in the room may require that a picture of neutral density 1 appear on the screen with a luminance of up to 100 foot-lamberts.

Assuming small losses in the projection lens and mirror, this defines the amount of energy which must pass through the illuminated area. The required light can be supplied by a Xenon arc lamp operating at about 5,000 watts. Since the Xenon lamp has a high luminous efficiency in the visible region, and contains relatively less infra-red than many other types, simply cooling the incident energy or filtering out the non-visible components will not solve the film heating problem. Film of density 1 will absorb 90% of the light energy and convert it to heat. This energy must be carried away from the film at a rate sufficient to keep the film in a safe temperature range—under 90°F.

We normally say there are three ways of transferring heat from one place to another—radiation, convection and conduction. Since simply blowing a stream of cold air on top of the film was, in our experience, not sufficiently efficient for this system, we further investigated the possibility of radiation transfer. Radiation from the film itself to neighboring cold plates at a refrigeration temperature of about 20°F. was considered. There could be, for instance, an annular plate around the light path coming up from the film to the projection lens. The amount of energy theoretically transferred to this cold plate was just on the edge of being adequate, and in combination with cold air across the film might have been good enough to prevent heat damage in the film. However, the cooling problem exists not only in simple viewers but also in precise measuring instruments. The presence of very cold regions next to the very hot illumination system resulted in temperature gradients which, we considered, would not be tolerable in a system for measuring imagery to micron tolerances.

The remaining possibility was a combined conduction-convection method, with a flowing fluid in contact with the hot film. Although liquid cooling obviously introduces many design problems and makes the mechanism more cumbersome, this method had been studied previously. Therefore, we also borrowed the idea which had first evolved from commercial contact printers, and began to investigate a liquid Freon film gate, in which the film is suspended between horizontal planes of laminar flow in a stream of liquid Freon. The Freon flows between parallel glass plates which form a platen or film gate containing the film and holding it in the viewing plane; it absorbs heat from the illuminated film area and recirculates through a heat exchanger where it is cooled again. Figure 1 shows the projector, with supply and take-up reels suspended in an enclosed tank. The right side contains the inlet for pressurized Freon, which flows through the platen area and into the left tank where it is pumped out again to the heat exchanger.

The spacing between the glass plates of the film gate is about 12 thousandths of an inch. with the film held in tension at the midway plane. Light passes through the film gate from the condenser system at the bottom, up through the projection lens to a mirror and then to a front viewing screen on the instrument. In the system now under construction, both projection and condensing lenses can be switched by a turret arrangement for a variety of magnifications. At the highest magnification, in order to utilize the light source efficiently, the light is concentrated into a much smaller area than the total film gate.

Pure Freon 113 was selected as the coolant, since it has a good combination of optical and thermal properties. It is colorless, not very toxic and has an index of refraction near that of the film itself. Therefore, scratches and other marks on the film itself are less visible in the projected image. A mixture of Freon and toluene has been frequently used in contact printers to eliminate the effects of scratches on old or often-used film.

Because of the solvent properties of Freon 113, all electrical components are in the room atmosphere, separated from the Freon by seals. No parts requiring normal lubrication can be used in the presence of Freon. Similarly, no electrical arcs can be permitted because of the possibility of decomposing Freon vapors and forming carbon deposits.

Figure 2 shows a schematic of the illumination and projection system. Light from the 5,000 watt Xenon arc lamp is directed by a quartz reflector through the initial condensing lenses of fused quartz. Ultraviolet radiation striking the reflector is transmitted back to the Freon-cooled lamp house. The first mirror is a dichroic filter or cold mirror which reflects visible light and transmits lower frequencies into a Freon-cooled heat sink behind the mirror. A conventional glass heat filter follows this to remove residual infra-red.

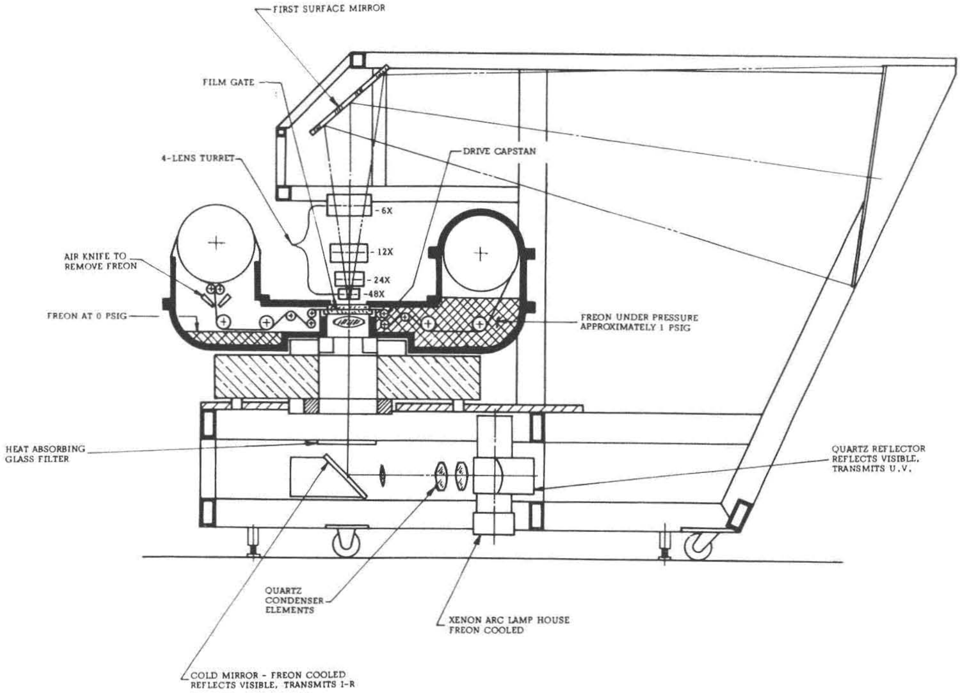

FIG. 1. Freon-cooled film viewer.

Above this, a lens turret controlled by pushbuttons on the panel brings in the appropriate final condensing lenses to illuminate an area on the film which will just fill the screen.

The total power available at the film plane from the 5 KW lamp is reduced to 50 watts of energy mostly in the visible region. The amount of energy absorbed in the film, and the resultant brightness on the screen depends on the average film density, but is independent of the illuminated area. If the film has density 1, 90% of the 50 watts, equivalent to 2.83 BTU/minute will be absorbed in any of the possible illuminated regions, from the largest (approximately a 7 inch circle) to the smallest (approximately a 1 inch circle). Therefore the *total heat* that must be removed from the region of the film does not depend on the magnification selected. However, at high magnification this energy is concentrated in a smaller portion of the film, so the system must be designed to remove heat at the proper rate for that maximum energy concentration.

One gallon of Freon 113 will absorb 40.245 BTU's in undergoing a temperature rise of 15°F. The film gate is 10 inches wide, but at the highest magnification only a 1 inch circle will be illuminated. We must consider an isolated strip of film of 1 inch wide in finding the proper flow rate over the illuminated region, and then provide the same flow rate over all other parts of the film. There are almost no tabulated data on heat transfer characteristics between a dielectric material and flowing Freon. Therefore we must make a number of assumptions in finding an estimate of the necessary flow rate.

One gallon per minute flowing over the "hot spot", if it absorbed all the heat energy, would rise in temperature about $\frac{15}{40}$ or $\frac{3}{8}$°F. per BTU. Since the input is 2.83 BTU per minute, the rise is

$$\frac{3}{8}\,\frac{°\text{F}}{\text{BTU}} \times \frac{2.83\ \text{BTU}}{\text{min.}} \times \frac{1\ \text{min.}}{\text{gal.}} = 1.06\,\frac{°\text{F}}{\text{gal.}}\,.$$

Now this is much less than the tolerable 15°F. rise, and it seems safe to allow a 2°F. rise in the local Freon, which would be permitted by a flow of $\frac{1}{2}$ gal./min. However, this is flow over only $\frac{1}{10}$ of the platen region, so total flow would be 5 gal./min. through the platen, since the "hot spot" may be anywhere on the film gate. This figure includes no allowance for conduction through the Freon, but does assume good conduction through the film-to-Freon interface.

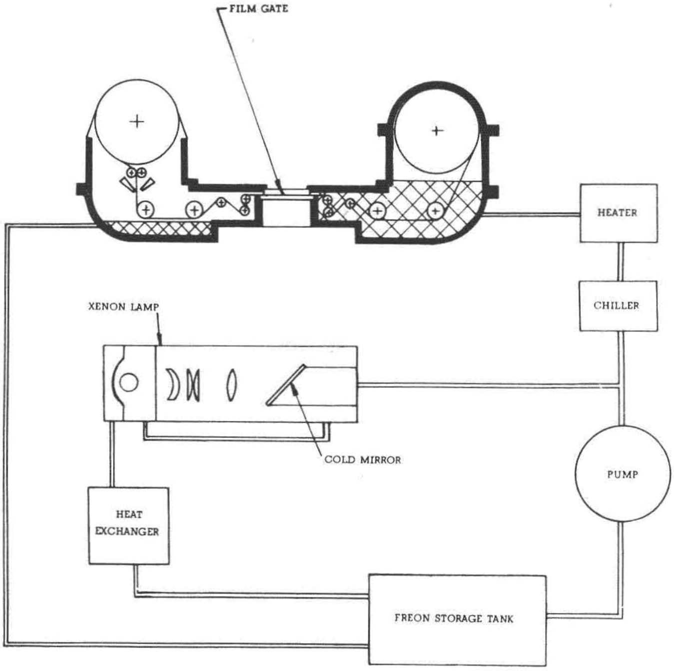

FIG. 2. Heat transfer system.

There are many assumptions and approximations in this figure, but experimentally it turns out that the average Freon temperature of the emerging fluid does indeed rise a few degrees F in the path of the hot spot. A typical linear coefficient of expansion for Estar base film is .0015 in./in.°F. If the film rises 2°F., in equilibrium with the Freon, then it will expand .006 inch in X and Y directions. This expansion will be modified by forces exerted through the surrounding film, which remains stationary, and by tension along the long direction of the film. A rough measurement of temperature rise can be made by using a thin strip of film (less than one inch wide) which is exposed for high density, with a few fiducial marks on either side, appearing as bright spots on the screen. At first the film will be at the inlet temperature of the Freon. As its temperature rises to the final equilibrium value, the marks will separate further, and their change in position can be measured on the screen.

This measurement is still affected by film tension and by the variation in temperature across the platen. An exact analysis of temperature distribution on the film and in the Freon is not yet made, and normal temperature measuring devices present considerable problems because of the space limitations and other conditions. However it appears that the measurement can be made by evaporating a series of thermocouples onto the surface of the film where the film itself has some known density pattern as well. Naturally, any metal evaporated onto the film would itself be an absorber and would change the average density in that region. However, small thermocouple patterns superimposed on a set of known densities would give us a way of approximating the temperature rise due to the film itself, and in the film itself.

What was first considered a major problem—that is, turbulence in the region of the film gate—has turned out to be less troublesome than expected. The flow pattern established across the gate is close enough to laminar that no fluctuations are seen at the high magnification and it seems possible to establish a smooth flow by using a centrifugal Freon pump. Figure 2 is a simplified schematic of the Freon system, showing the two major loops. The pump supplies Freon to the upper loop, the film cooling section, through a chiller-heater combination. The heater is controlled by a thermostat at the entrance to the pressurized section of the film tank, which holds the temperature at 70°F. This Freon returns to the common storage tank. A second loop after the pump provides a considerably higher flow rate (about 8 gal./min.) to the pre-cooling system of the illumination optics. This flows first through a small heat exchanger behind the dichroic mirror, where it picks up heat generated by the absorption of infra-red passing through the mirror. It then flows through the lamp housing, and also collects heat produced by the absorption of ultra-violet which has passed through the quartz reflector.

The flow rate is chosen to accommodate more than the 5,000 watt (280 BTU/min.) lamp output, most of which converts to heat in the illumination optics. This type of Freon vaporizes at 117°F., so it must be kept below this temperature throughout the entire loop. A flow of 8 gal./min. can carry off 320 BTU/min. with a temperature rise of 15° over the tank temperature, which is close to ambient, or about 75°F. The heated Freon from this loop goes through an air-cooled heat exchanger, where its temperature is reduced to less than 80°F., and then mixes with the film-cooling Freon in the tank.

The applications of this cooling method extend from simple viewers to high-precision measurement. Experience with the prototype system indicates that the Freon-cooled film viewer will be stable enough to place on a high accuracy measuring machine, where it could give the photointerpreter very wide intensity variation on a machine which can also measure and record film coordinates.

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Visual Factors (continued from page 999)

perimental room, as evidenced by the production increase, other equally important advantages exist. These include the ease of supervision (from the standpoints of both the supervisor and the compiler), the generation of a strong cohesive or "team" feeling, and the possibilities of more efficient utilization of available space. The Rocky Mountain Area of the Geological Survey will utilize this design when additional space is available in the near future.

It is recommended that the number of plotting units in this type of environment be reduced to 12 instruments per room. This is about the size of one supervisory unit and lends itself to an effective positioning of plotting instruments. Through the research study it was found that lighting conditions, closely approaching those created in the experimental room which produced our best results, can be attained by properly spaced and baffled light sources without resorting to expensive dimming equipment.

SUMMARY

The results of this research are of serious concern to the professions of photogrammetry and optometry. There are additional areas for study that could not be compressed into this research project.

Photogrammetry must continuously study the visual abilities of stereocompilers, particularly those engaged in making precise measurements at extremely low light levels. Environmental conditions, particularly in regard to ambient light, should be carefully controlled. Group stereoplotting rooms appear to have definite advantages over isolated units.

Optometrists must be thoroughly educated to appreciate the stringent visual requirements demanded by stereocompilation operations. This is being accomplished by seminars and work groups conducted by the professional societies.

1965 Convention: March 28—April 3. See page 1052.