the CSF, measured behaviorally, exhibits a characteristic shape (for example, Fig. 2C). The peak of the CSF refers to the spatial frequency where the highest contrast sensitivity occurs. At lower frequencies, decreasing contrast sensitivity results in a low-frequence falloff. At higher frequencies, contrast sensitivity also decreases. The frequency at which high frequency sensitivity falls off to a value of 1.0 is referred to as the cutoff spatial frequency. The cutoff frequency represents the limit of resolution of a 100 percent contrast sinusoidal grating; its value is closely related to grating acuity, which is usually measured with high-contrast square-wave gratings.

4. M. Banks and P. Salapatek, *Invest. Ophthalmol. Visual Sci.* **17**, 361 (1975); J. Atkinson, O. Braddick, K. Moar, *Vision Res.* **17**, 1037 (1977); M. Pirchio, D. Spinelli, A. Fiorentini, L. Maffei, *Brain Res.* **141**, 179 (1978).
5. Two problems encountered when using CRT display systems are (i) the relationship between input voltage and output luminance is not linear, and (ii) the spatial frequency response function is not flat over the frequency range of interest. Our computer-controlled display system was calibrated and then programmed to compensate for both the nonlinearity and the frequency response.
6. For a general discussion of the development of the face mask technique for studying perception and learning in infant monkeys, see G. P. Sackett, R. Tripp, C. Milbrath, J. Gluck and H. Pick [*Behav. Res. Methods Instrum.* **3**, 233 (1971)]. For an application of the method to visual psychophysics experiments in infant monkeys, see R. Boothe, D. Y. Teller, and G. P. Sackett [*Vision Res.* **15**, 1187 (1975)].
7. There may, of course, be a low-frequency falloff below the range tested. Apparatus limitations prevented us from presenting gratings of lower frequency with an adequate number of cycles. We have recently modified our apparatus so we can present lower spatial frequencies with sufficient numbers of cycles. Preliminary indications from a single infant are that frequencies as low as 0.2 to 0.4 cycle/deg must be used before a low-frequency turndown can be detected in young infant monkeys.
8. Anatomical changes take place in the macaque monkey visual system during the same postnatal period during which we have found the behavioral CSF to be changing. The retina changes postnatally in density, size, shape, and in the ultrastructure of foveal cones [T. Samorajski, J. R. Keefe, J. M. Ordy, *Vision Res.* **5**, 639 (1965); A. Hendrickson and C. Kupfer, *Invest. Ophthalmol.* **15**, 746 (1976)]. In the striate cortex, there are changes in dendritic arborizations and in the numbers of presumed connections between neurons [J. S. Lund, R. G. Boothe, R. D. Lund, *J. Comp. Neurol.* **176**, 149 (1977); R. G. Boothe, W. T. Greenough, J. S. Lund, K. Wrege, *ibid.* **186**, 473 (1979)].
9. Clarity of the optics, eye size, and accommodative response might all play a role in the development of the CSF, but all of these factors are probably minor in relation to the size of the effects found. The optics of the infant monkey eye are clear at birth by ophthalmic examination. Measurements of the optical line spread function reveal that optical quality is very good within days after birth and resembles that of the adult by 2 months (R. A. Williams and R. G. Boothe, in preparation). An increase in axial length between 4 and 20 weeks of age increases retinal image size by a factor of about 1.14, a magnification much too small to account for the observed changes in the CSF. It is not known whether infant monkeys can accurately accommodate to our stimuli. However, the data shown in Fig. 2, A and B, were obtained at two different viewing distances, 60 and 120 cm respectively. The similarity of the two sets of data leads us to believe that accommodation also contributes little to the developmental trends shown.
10. L. Mayer and V. Dobson, in preparation.

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Thermocline Temperature Differences and Realizable Energy

The report by McNichols *et al.* (*1*) seems too superficial in its treatment of a relatively simple analysis. My first objection is to applying Carnot efficiency calculations to the total system of heat exchangers and expansion engine. Strictly speaking, the Carnot analysis applies only to the expansion engine. The gross temperature difference must then be allocated between the heat exchangers and the expansion engine.

The TRW Systems Group deals in some detail with this matter in their Ocean Thermal Energy Conversion (OTEC) report (*2*). The OTEC temperature levels and temperature differences are of the same general order of magnitude as those used by McNichols *et al.* (OTEC temperature levels and temperature differences may be slightly higher). The allocation of the total temperature difference used by TRW is 50 percent to the heat engine and 50 percent to heat exchanger energy transfer. Two important considerations flow from this allocation. The first is that all of the gross energy carried by the warm water leaving the working-fluid boiler bypasses the generating unit entirely. Therefore, the energy actually transferred into the working fluid is already only a small portion of the gross energy originally available.

The second consideration is that the Carnot efficiency must be calculated for the temperature differences and levels associated with the expansion device. Only after the Carnot efficiency is calculated on the basis of a consideration of the appropriate data is it correct to apply the realization factor of 50 percent to the Carnot efficiency.

In short, the report by McNichols *et al.* fails to recognize that Carnot thermal efficiency is only a part of the entire analysis. The conversion of gross temperature difference to equivalent head, although mathematically correct, is essentially meaningless because energy quantity depends upon both head and flow quantity. When allowance is made for the fact that most of the gross heat quantity never reaches the conversion device and the appropriate temperature difference across the expansion engine is used, then the effective head is only on the order of one-tenth that shown in (*1*, p. 168). Clearly, an equivalent effective head of 16 m is not nearly as impressive as a potential head of 160 m. It is unfortunate that this fragmentary analysis did not include a consideration of the importance of relating the head to the correct flow quantity when discussing realizable energy quantities.

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2. TRW Systems Group, *Ocean Thermal Energy Conversion Research on an Engineering Evaluation and Test Program* (Publication PB-246 178, National Technical Information Service, Springfield, Va., 1975).

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In their report on the use of the thermocline temperature differences in hydroelectric reservoirs, McNichols *et al.* (*1*) overstate the potential power output by a factor of $\gtrsim 8$. It is clear from their report that they consider only the use of the normal outflow of water (for if recirculation back into the reservoir is allowed, the system reduces to an Ocean Thermal Energy Conversion type concept with outputs limited only by solar input and system size). For such an application, the assumption of a value $\Delta T/T$, where T is absolute temperature, for Carnot efficiency is incorrect, since the heat source and sinks are finite. The hot and cold water flows approach one another in temperature so that the effective mean temperature difference is less than ΔT.

For a mass flow rate of m (in kilograms per second), of which a fraction α is at a temperature $T + \Delta T$ and $1 - \alpha$ is at T, the maximum (Carnot) mechanical power output P (in watts) is given by

$$P = mC[T + \alpha\Delta T - T^{1-\alpha}(T + \Delta T)^{\alpha}] \approx mC\Delta T \frac{\Delta T}{T}\alpha\frac{(1-\alpha)}{2} \text{ for } 0 \leq \frac{\Delta T}{T} << 1 \quad (1)$$

where C (in joules per kilogram per kelvin) is the specific heat of water. The extra factor $\alpha(1 - \alpha)/2$ in Eq. 1, compared with equation 3 in McNichols *et al.*, leads to my statement above.

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10 May 1979

We agree with Hall and Crouch that the effective ΔT loss (T is the absolute temperature) associated with removing heat from water must be included in any detailed analysis of a real thermal energy conversion system, along with many other thermodynamic, economic, and environmental considerations. We strongly disagree, however, that inclusion of this ΔT loss necessarily reduces the achievable head (for a thermocline temperature difference of 15°C) to about 16 m. The actual effect depends on the system design and heat engine performance.

Apparently, Hall, Crouch, and we agree that the net available equivalent head (in meters) (for the example of a 15°C temperature difference) is given by $320f$, where f is the system efficiency as a fraction of the theoretical maximum (*1*). We maintain that f depends on the system design and is not limited by fundamental thermodynamic considerations to 1/20 [the value obtained by Hall for the Ocean Thermal Energy Conversion (OTEC) Rankine system does provide a base line, and it is up to anyone proposing an improved system to show that an $f > 1/20$ (or some other advantage) can be achieved.

The OTEC system was designed to optimize the ΔT allocations so as to minimize the capital cost per unit power produced, and ". . . the cost and performance of heat exchangers dominate system economics . . ." (*2*). This optimization, for the OTEC Rankine system, requires that the source and sink water flow through massive heat exchangers once, and any remaining heat is discarded. The OTEC studies convincingly show that this system will reduce the net output, for a total ΔT thermal source of 15°C, to ~ 16 m of equivalent head. (Even with this limitation, the thermocline resource would provide a significant new power source.) However, this result is not fundamental, and the minimum cost design for systems that use non-Rankine heat engines will call for different values of f. For example, the Nitinol heat engine, to which we referred in (*1*), utilizes a solid metallic alloy as working medium. The working material is corrosion-resistant and can be placed directly into contact with the hot and cold water, and the resistance to heat transfer per area between water and Nitinol is much less than that for water–heat exchanger–working fluid for the two-phase Rankine system. Therefore, both the 50 percent loss in ΔT quoted by Hall for the OTEC Rankine heat exchangers and the heat exchanger costs are essentially eliminated for the Nitinol heat engine system. The first elimination will increase f directly, and the second will certainly modify the optimum ΔT allocation at a lower cost level.

Crouch's argument also applies to particular types of systems and therefore does not provide a fundamental limitation to thermocline energy conversion. For example, consider a system for which only the warm water from near the reservoir surface is included in the reservoir outflow, and the system heat sink is provided by cold water which flows from below the reservoir surface through the dam to the heat engine and is then returned through the dam to the reservoir. This system would result in an essentially infinite heat sink. (Parasitic pumping losses must be considered in cost optimization.) For this case, an analysis just analogous to that by Crouch results in a factor of 1/2 which multiplies the theoretical maximum power, instead of the 1/8 for the type of systems analyzed by Crouch.

Our purpose in (*1*) was to report the equivalent head available from solar-produced lake thermoclines, not to discuss factors that depend on the specific type of heat engine system selected for that application. The results of the OTEC Rankine studies should not be used as a basis for discarding a valuable energy resource. Rather, they should be utilized to focus attention on the development of non-Rankine heat engines and systems that are optimized for commercial utilization of the valuable thermocline thermal energy resource.

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