Energy: Calculating the Risks

My attention has been drawn to the 23 February issue of *Science* and the article "Risk with energy from conventional and nonconventional sources" by Herbert Inhaber (p. 718). I was commissioned by the Atomic Energy Control Board of Canada to review Inhaber's original report (*1*) after it had been sent out to be printed. My review was constructively critical and is available as AECB Report 1131, dated 27 March 1978.

My overall impression of Inhaber's work at the time was as follows:

> . . . the author did not challenge his own assumptions in the report as to how his conclusions may be altered. Nor were any alternative interpretations of the methodology presented. In this regard, the report may become subject to criticism, especially since the conclusions depict conventional energy systems to be less risky than the non-conventional ones. As this review will show, other interpretations of the methodology of risk accounting can lead to the opposite conclusion.

In the year since my review, Inhaber's report has been widely circulated and has been summarized, excerpted, and quoted as an authoritative study. But, is it really?

Before starting my review, I asked Inhaber to tell me how much effort went into the study. He replied that the report had been prepared during a 3-month period and required a total of 3 to 4 man-months of effort by Inhaber and a research assistant. Inhaber has published revised versions of his initial report, but the revisions have all been in the area of correcting data and calculations. There have been no additional revisions or improvements of his risk-accounting methodology.

There are several serious problems with Inhaber's methodology:

1) Inhaber includes *all* of the risks associated with materials acquisition, component fabrication, and on-site construction of energy facilities. This implies that every industry making or transporting anything connected with the facility would not be doing anything else if that facility was not built. I submit that only the *incremental* risks in constructing any energy system should be measured, not the gross.

2) Inhaber's "nonconventional" energy systems include an energy backup in the form of conventional energy. This might be acceptable if the risk contribution of the backup system were small in proportion to that of the nonconventional system. But is it? If one looks at figure 7 of Inhaber's original report (figure 4 of his article, one can readily see that, for wind, solar thermal, and solar photovoltaic, the energy backup systems contribute the majority of risk! Therefore, in view of the overwhelming risk contribution of conventional backup systems to the so-called nonconventional systems, Inhaber is not truly comparing conventional with nonconventional.

3) If one uses Inhaber's data as is, removal of the risks of creating an energy facility and the risk due to the backup system has the effect of *reversing* his conclusion. That is, nonconventional systems (which they now are because backup has been removed) are less risky than conventional systems. This demonstrates how *sensitive* Inhaber's methodology is to the validity of the assumptions upon which it is based.

The nuclear industry has made wholehearted reference to the Inhaber report as proof positive that nuclear energy systems are safer than nonconventional systems. There appears to be no questioning at all of Inhaber's surprising "pro-nuclear" conclusions. This can only serve to diminish the credibility of the nuclear industry.

REIN LEMBERG
Lemberg Consultants Limited,
1150 Cynthia Lane,
Oakville, Ontario L6J 6A6, Canada

References

1. H. Inhaber, *Risk of Energy Production* (AECB 1119, Atomic Energy Control Board, Ottawa, Canada, 1978).

I found Inhaber's article to be surprisingly at odds with my own similar study (*1*) of electric energy systems. About half of his source material and the methodology he claimed as his own is taken from work I technically directed or had contracted at the Jet Propulsion Laboratory (JPL) (*1, 2*). Thus, I feel knowledgeable about the information and approach Inhaber used in his study.

When I received his late 1978 report (*3*), which the *Science* article summarizes, I found remarkable disagreement between results I obtained when I used the JPL study team data and the results Inhaber derived. For example, his estimates of total health risk (*4*) compared to those in the JPL final report were (i) a factor of about 15 greater for coal; (ii) a factor of about 100 greater for solar thermal electric; and (iii) a factor of about 100 greater for solar photovoltaic. However, his results were about the same for the health risk from a nuclear plant.

I notified him immediately, pointed out these enormous differences, and asked what the nature of the disagreement might be. He indicated that he had added a few things that were left out of the JPL analysis but did not identify even in a general way what these left-out factors might be. Since I had spent 3 years developing the data and had had the assistance of about 20 professionals, I expressed skepticism and advised him not to publish any further without checking his analysis. When I noticed his article about a year ago in *New Scientist* (*5*) without any substantial changes, I wrote to each member of the Canadian Atomic Energy Control Board warning them of potential inaccuracies in Inhaber's work. However, they continued to support him.

I believe the review process used by the scientific community in this case was inadequate. I am open to suggestions as to how this can be avoided in the future.

RICHARD CAPUTO
Jet Propulsion Laboratory,
Pasadena, California 91103

References

1. R. Caputo, *An Initial Comparative Assessment of Orbital and Terrestrial Central Power Systems* (Report 900-780, Jet Propulsion Laboratory, Pasadena, Calif., March 1977).
2. K. R. Smith, J. Weyant, J. P. Holdren, *Evaluation of Conventional Power Plants* (Report ERG 75-5, Energy and Resources Program, Univ. of California Press, Berkeley, July 1975).
3. H. Inhaber, *Risk of Energy Production* (AECB 1119, Atomic Energy Control Board, Ottawa, Canada, 1978).
4. Total health risk in units of man-days lost per unit of electric energy generated (megawatts electric times the number of years) due to disease, accident, and death over the entire life cycle of the energy system.
5. H. Inhaber, *New Sci.* **78**, 444 (1978).

More correspondence concerning Inhaber's article will be published in a subsequent issue.—EDITOR

Fringe Benefits of Cataract Surgery

Persons facing lens removal because of cataracts frequently view their future with some alarm. To them and in particular to professional colleagues who have this problem, we say, "Cheer up. You'll have advantages you never expected." We hope that ophthalmologists will become aware of the morale value of informing their patients of the phenomena to be described and of the exciting new perceptual capabilities resulting therefrom.

Recently, after cataract surgery, one of us (D.D.) became acutely aware of these capabilities. His work requires the rapid examination of numerous, relatively small objects in museum exhibitions. When the object is behind the glass of a show case, the viewer often cannot get

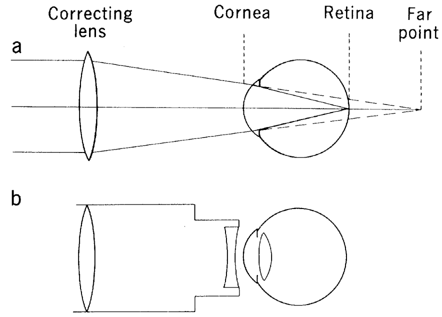

Fig. 1. (a) The aphakic eye corrected by a converging lens. Any lens that would, in the absence of the eye, form an image at the far point will serve to correct aphakia. (b) A Galilean telescope and a normal eye. With an appropriate choice of lenses, this system is the optical equivalent of the one shown in (a) (not drawn to scale).

close enough to resolve its detail. Purely fortuitously, Davenport, having forgotten to put the contact lens in his lensless (aphakic) eye, discovered that with the detachable lens from a monocular bird glass, he could get excellent resolution of small objects 50 to 100 centimeters away at a magnification of ×2 to ×3. He was also surprised to find that simply by changing the distance of this lens relative to his lensless eye, he could obtain clear focus for objects at all distances beyond a few centimeters. In addition, ever since the surgery he has been struck by a second phenomenon. The world seen through his aphakic eye is brighter and more vividly colored than that seen through his normal eye. The blues in particular stand out. Oddly enough, none of these phenomena had been mentioned to him by his ophthalmologists nor by other aphakics, so he brought them to the attention of the other of us (J.M.F.), a specialist in visual perception.

Actually, these phenomena have relatively simple optical explanations, which, although well known to visual scientists, deserve to be more widely known. In the normal eye, light rays are bent inward so as to form a sharp image on the retina. Most of this bending is done by the front surface of the eye (cornea). The rest is done by the lens, which before middle age varies in shape so as to focus objects at different distances (accommodation). An eye without a lens does not bend light enough to bring any object into focus. A sharp retinal image may be restored by placing an artificial converging lens in front of the aphakic eye. There is a wide range of lens powers (power is the reciprocal of the focal length in meters) that will do this, provided that each is held at an appropriate distance in front of the eye.

To understand why a single lens can be so useful in aphakia, one must understand the relation between the lens power and the lens distance required for its correction. There is a point behind the aphakic eye (its *far point*) such that rays converged toward this point by a correcting lens will be focused by the aphakic eye on its retina (Fig. 1a). (The far point is not to be confused with the focal point of the eye, also behind the eye in aphakia, which is the point at which rays parallel to the axis will be focused.) The far point is about 8 cm behind the cornea of the aphakic eye. Any lens which would, in the absence of the eye, form an image of the object at the far point will, together with that eye, bring the image into focus on the retina. The relation between the focal length of the lens, f, the distance from the lens to the object, d_o, and the distance from the lens to the image, d_i, is given by the well-known Gaussian lens formula $1/f = 1/d_o + 1/d_i$. Here the image distance is the distance from the correcting lens to the far point. Table 1 gives some solutions to this equation both for a distant object and one at 72 cm. Note that the distances in the table are measured from the cornea (that is, $d_i - 8$ cm).

These lenses not only bring the image into focus in the aphakic eye, they also magnify it. Magnification is the ratio of image size to object size, which is equal to the ratio of image distance to object distance, both distances being measured from the lens. What is of interest here is not the magnification per se, but relative magnification, that is, the ratio of magnification in the corrected aphakic eye to that in the normal eye. To determine this we need only consider the image formed at the far point by the correcting lens alone and the image formed at the same point by a lens located at the position of

Table 1. Correction of aphakia. Approximate relation between correcting lens distance, focal length, and magnification (compared to the normal eye) for a distant object and for one at 72 cm.

Distance lens to cornea (cm)	Distant object: Focal length required (cm)	Distant object: Magnification	Object at 72 cm: Focal length required (cm)	Object at 72 cm: Magnification
2	10	1.4	8.8	1.4
4	12	1.6	10.2	1.8
8	16	2.2	12.8	2.5
16	24	3.3	16.8	4.3
32	40	5.5	20.0	10.0
48	56	7.7	16.8	23.0
56	64	8.8	12.8	40.0
60	68	9.3	10.2	57.0
62	70	9.6	8.8	70.0

the normal lens, about 7.3 cm in front of the far point (*1*). Values of magnification for a distant object and one at 72 cm are given in Table 1.

It is clear that for a distant object the farther the lens is held from the eye, the greater the required focal length and the greater the magnification. For an object at 72 cm the required focal length at first increases and then decreases as the lens is held farther in front of the eye. Since magnification increases with lens distance, one might think the farther the better. However, in addition to the awkwardness of holding a lens far from the eye, there is also the disadvantage that the field of view decreases with lens distance. A more practical solution for many purposes is a lens with a focal length of about 16 cm (power, +6.25 diopters). With such a lens an aphakic eye can (i) focus far objects with a magnification of ×2; (ii) when moved farther out from the eye, focus near objects with a magnification of ×4; and (iii) when moved out still farther, focus near objects with a magnification of more than ×20. The range of distances that this lens can focus is infinity to 59 cm. What a remarkably useful optical instrument a simple lens becomes when combined with an aphakic eye! Of course, magnification is not always desired. To minimize it, a high-power lens must be close to the eye. This is one reason why contact lenses are often used to correct aphakia; they magnify only about 10 percent.

In practice a simple lens will produce aberrations which reduce image quality. Quality can be improved by using a lens system consisting of two or more elements designed to reduce aberration. Davenport gets excellent image quality by use of an achromatic projector lens system (50 millimeters in diameter) with a focal length of 15 cm. The metal tube which holds the lenses also serves to reduce stray light. These advantages are obtained at the cost of more bulk and a slightly higher price ($10 secondhand at a photography shop).

Why cannot the normal eye get the same advantage from a comparable system? Put simply, any lens that produces appreciable magnification also changes the vergence of the rays. This tends to put objects out of focus for the normal eye, but in focus for the aphakic eye. The normal eye needs at least two lenses to achieve the same result. The simplest system that does this is the Galilean telescope (Fig. 1b). This consists of a converging lens (objective) and a diverging lens (eyepiece) usually mounted in a variable length tube. The Galilean system has essentially the same optical properties as the converging lens–aphakic eye system. The reason for this similarity is that removing the lens of the eye is optically equivalent to adding a diverging lens. In effect, cataract surgery provides the aphakic person with a built-in eyepiece.

Finally there is the second fringe benefit of cataract surgery, the enhancement of color and brightness. The normal lens absorbs light of all wavelengths but particularly in the blue, and this absorption increases with age (*2*). When the lens is removed this light reaches the receptors, producing larger responses particularly in the short-wavelength cones. In addition ultraviolet light, normally almost completely absorbed by the lens, now reaches the retina (*3*). This has two effects. It is absorbed directly by the short-wavelength cones producing a violet sensation, and it causes the retina to fluoresce, producing visible light of a wide range of wavelengths up to 600 nanometers. This light appears greenish blue. One is reminded, however, that high-intensity ultraviolet may be damaging to the unshielded aphakic eye.

In summary, the aphakic eye both transmits more light than the normal eye and, aided by a simple converging lens, can produce sharp retinal images with a wide range of magnification. These properties add greatly to esthetic enjoyment, particularly for the flower lover (*4*), collector of small insects, jewel fancier, or "museum-watcher." Davenport may be one of the few persons in the world who, when he went to the Tutankhamon exhibit, *took out* his contact lens.

DEMOREST DAVENPORT
Department of Biological Sciences, University of California, Santa Barbara 93106

JOHN M. FOLEY
Department of Psychology, University of California, Santa Barbara

References and Notes

1. Relative magnification is $d_i d'_o / d_o d'_i$, where d_i, d_o refer to the image distance for the correcting lens and d'_i, d'_o to these same distances for a lens 7.3 cm in front of the far point (that is, d'_o = 7.3 cm). When the object is very far away, $d_o \approx d'_o$ and relative magnification is d_i / d'_i.
2. Y. Le Grand, *Light, Color and Vision* (Chapman & Hall, London, 1968).
3. G. Wald, *Science* **101**, 653 (1945).
4. In a recent brief experiment, in which with his aphakic eye and contact lens Davenport observed through a filter with an upper cutoff at 360 nanometers a sunbathed flower of the Carolina jasmine *(Gelsemium sempervirens)*, he could clearly discern the pattern of the ultraviolet-reflecting ("honey-guide") tissue of the petals. "*One side*, bees!"

Erratum: A report described in the 27 April issue (News and Comment, p. 389) was incorrectly identified. It was coauthored by Rosemary Chalk and Frank von Hippel for the Committee on Scientific Freedom and Responsibility of the AAAS and will be published in a forthcoming issue of *Technology Review*.