Conclusions

The technology of acoustic microscopy has now been advanced to the point where it can be used to record micrographs of cells and of cell complexes. The acoustic microscope responds to the elastic properties of the specimen and it therefore provides information which is distinct from that of an optical microscope. We believe that this instrument can be used in the fields of biological and medical research to obtain new information or to obtain some information more rapidly than is possible with present techniques.

The micrographs we have presented show that unstained biological material can be acoustically imaged with good contrast. Certain materials such as collagen and connective tissue have a particularly marked attenuation. As a result, the acoustic microscope can reveal information that is now only available through time-consuming staining techniques. Recently it has been shown that the acoustic microscope is compatible with frozen sectioning techniques and, with proper development, this may provide improved diagnostic techniques.

That the absorption of acoustic energy is proportional to the viscosity of the medium can be of particular importance in investigating living systems (*11*). It might be possible to use the acoustic microscope for monitoring the viscosity within the cytoplasm of cells undergoing mitosis. The acoustic microscope might also be useful for monitoring the various rheological states of the contractile systems that are responsible for movement in several cellular systems. An increased understanding of the rheology of protoplasm or of cell division is a goal worthy of a large and extended effort.

With the work that has been done to date it is not possible to pinpoint the possible areas of application with great accuracy, but we do claim to have demonstrated that this is a new method for viewing the microscopic world. With this in mind it is important to examine carefully the features and limitations of this new tool and to search for areas where it can be used to extend our knowledge.

References and Notes

1. A. Korpel, in *Ultrasonic Imaging and Holography*, G. W. Stroke, W. E. Kock, Y. Kikuchi, J. Tsojivchi, Eds. (Plenum, New York, 1974), pp. 345–362; L. W. Kessler, *J. Acoust. Soc. Am.* **55**, 909 (1974); R. K. Mueller (*Inst. Electr. Electron. Eng.*) *Proc.* **59**, 1319 (1971). These reviews cover the state of the art of acoustic microscopy up to the spring of 1973. The series entitled *Acoustical Holography* (Plenum, New York, 1970–1974), vols. 1 to 5, contains several articles on the various ideas that have been put forth for an acoustic instrument.
2. R. A. Lemons and C. F. Quate, *Appl. Phys. Lett.* **24**, 165 (1974).
3. E. L. Carstensen and H. P. Schwan, *J. Acoust. Soc. Am.* **51**, 305 (1959).
4. A clear demonstration of this effect for low frequency sound has been given by Anderson where he compares the attenuation in liquid blood with the absorption in an organized blood clot [R. E. Anderson, in *Acoustical Holography*, P. S. Green, Ed. (Plenum, New York, 1974), vol. 5, p. 508, fig. 3].
5. This has been pointed out by F. Dunn and W. J. Fry in *The Encyclopedia of Microscopy*, G. L. Clark, Ed. (Reinhold, New York, 1961), p. 544; and even earlier S. Sokolov recognized this potential for an acoustic imaging system [see G. Devey, *Radio-Electron. Eng.* (a translation) (February 1953), p. 8].
6. R. A. Lemons and C. F. Quate, *1973 Ultrasonic Symposium Proceedings*, IEEE Cat. 73CHO807-8 SU (January 1974), paper E-6, pp. 18–21.
7. E. M. Slayter, *Optical Methods in Biology* (Wiley Interscience, New York, 1970), p. 241.
8. W. Bloom and D. W. Fawcett, *A Textbook of Histology* (Saunders, Philadelphia, ed. 9, 1968).
9. R. A. Lemons and C. F. Quate, *Appl. Phys. Lett.* **25**, 251 (1974).
10. R. Kompfner and R. A. Lemons, in preparation.
11. A. D. Keith and W. Snipes, *Science* **183**, 666 (1974); R. D. Allen, *Acta Protozool.* **11**, 75 (1972). These authors include a discussion of the various techniques that have been used in the past to measure the rheological properties of cells.

12. The research was funded by a grant from the John A. Hartford Foundation, Inc., and we are grateful for that support. Drs. N. K. Wessells, L. Hayflick, R. Dorfman, R. Kempson, and M. Billingham gave us great encouragement and pointed to areas of possible utility. Drs. E. Farber and F. Ebaugh guided us in the work with cell complexes and tissue sections. The cell cultures of Fig. 6A were prepared in Dr. Hayflick's laboratory (Department of Medical Microbiology) and the tissue sections were prepared in Dr. R. Lawson's laboratory (Department of Pathology). Dr. W. Bond taught us how to fabricate and accurately assemble the components of the prototype. Dr. R. Kompfner originally suggested this project to us, and he and Dr. M. Chodorow were of great help in discussions concerning the physics of imaging.

NEWS AND COMMENT

Nuclear Proliferation: India, Germany May Accelerate the Process

As representatives of 69 nations meet in Geneva this month to review the status and ponder the future of the 1970 Non-Proliferation Treaty (NPT), awareness is growing that further restraint on the spread of nuclear weapons may depend as much on controlling technology as on guarding world commerce in the fissionable fuels—uranium and plutonium. Certainly this was a cardinal lesson of India's first nuclear explosion a year ago. India, after all, got its plutonium not by theft but openly from a Canadian-supplied reactor and is building more reactors based on Canadian technology.

While the Geneva meeting continues, two imminent events promise to lend a grim new aura of urgency to controls on nuclear technology. For one, knowledgeable U.S. officials believe that India is prepared to detonate its second nuclear explosion. At the same time, West Germany is on the verge of concluding an agreement with Brazil that would provide Latin America's largest nation not only with the technology it needs to become self-sufficient in nuclear energy but would also endow Brazil with the technological base from which, if it saw fit, to build nuclear weapons.

Like India, Brazil has refused to sign the NPT, under which it would be obliged to foreswear development of nuclear explosives and submit to international inspection of its nuclear facilities. Brazil's government has maintained the position that the NPT discriminates against nonnuclear powers. Various Brazilian government officials since the late 1960's also have asserted a right to build and detonate "peaceful" nuclear explosives.

Informed U.S. officials believe that both the Indian nuclear test and the signing of the West German–Brazilian technology agreement are being delayed now only for diplomatic reasons, possibly in deference to the NPT review conference, which ends on 30 May. West Germany and Brazil are participating in the conference, but India is not. India is believed to recognize that it has little to gain by an act that would inevitably be interpreted as a calculated insult to conference participants and a blow to the treaty itself. Also, India is just now reaching an understanding with Canada that could lead to a resumption of nuclear cooperation between the two countries. Even so, the second Indian explosion is regarded as imminent. "It could be days, it could be weeks," one U.S. official told *Science*. "It's just a matter of when they decide to push the button."

Similarly, or so it seems, "all systems are go" with the West German–Brazilian deal, worth by some estimates as much as $8 billion over the next 10 to 15 years.

Of the two developments, the pending agreement between West Germany and Brazil may have the greater significance for the proliferation problem. Details are sketchy, but the agreement apparently grew out of talks that began last November between the Brazilian government and a consortium of German firms. The *Folha de São Paulo*, a well-regarded São Paulo newspaper, reported on 27 March that the agreement "will involve all aspects of nuclear technology, from prospecting for radioactive minerals, uranium enrichment, and reactor production all the way to fuel reprocessing."

Government and industry sources in the United States say the deal appears to include the sale of as many as eight 1200-megawatt pressurized water reactors of German design to be built over the next 10 to 15 years (Brazil's first nuclear power plant, a 626-megawatt Westinghouse facility, is scheduled to start up in 1977). More important from the arms controller's point of view is the inclusion of a "complete package" of nuclear fuel facilities—a fuel fabrication plant, a chemical reprocessing plant for extracting plutonium from spent fuel, and a uranium enrichment plant for concentrating the fissionable isotope uranium-235.

The uranium enrichment plant contemplated in the agreement would be based on the "jet nozzle" process developed gradually since the mid-1950's, first at the government-supported Karlsruhe Nuclear Research Center and, since 1970, by the large energy combine of STEAG, AG in Essen (see box below). If the sale of a nozzle enrichment plant goes through, it will mark the first commercial development of this dark-horse competitor with gaseous diffusion and the gas centrifuge, the two enrichment processes currently working on a commercial scale.

The last two items in the German package worry arms control analysts more than anything else. Reprocessing and enrichment plants are the most logical targets for attempts to divert fissionable fuels, either by a government bent on joining the nuclear club or by terrorist factions. For this reason, the U.S. government has discouraged U.S. companies from exporting reprocessing technology and has only recently been willing to share enrichment technology, and then only under closely controlled circumstances.

The Bonn government, however, has adopted a more relaxed attitude, as is in-

"Nozzle" Enrichment for Sale

Dozens of different methods have been devised since the 1940's to enrich uranium. In each the objective is the same—to concentrate fissionable uranium-235 for use in reactor fuel or weapons. Two of these methods, gaseous diffusion and the gas centrifuge, have proved economical in commercial plants. But the West German "nozzle" or aerodynamic process now appears not only to be economically competitive but also technologically simpler than the other two.

Several variations of the nozzle process exist, but the one closest to commercial application works like this:

Uranium hexafluoride gas (mixed with hydrogen) is pumped through a long slit, forming a rapidly moving sheet of gas. The gas strikes a curved wall, bending the sheet through 180 degrees. Centrifugal forces then carry the heavier uranium-238 (which makes up 99.3 percent of the gas) to the outer surface of the sheet, where a knifelike barrier pares it off. The lighter fraction, now slightly enriched in uranium-235, is routed through hundreds of additional stages to reach the desired level of enrichment—about 3 percent uranium-235 for the fuel of light-water reactors or more than 90 percent for gas-cooled reactors or weapons.

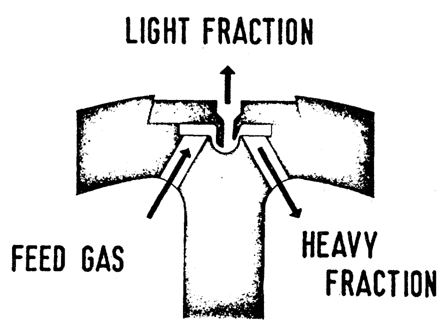
Advantages of the nozzle process are that it does not require the hard-to-make porous barriers of a gaseous diffusion plant and that it avoids the highly stressed moving parts of an ultracentrifuge. One disadvantage of the nozzle process is that it consumes almost twice as much electric power as a gaseous diffusion plant and 20 times the power of an equivalent centrifuge plant. This disadvantage wanes, however, where electric power is cheap (even if inconveniently located), as in Brazil.

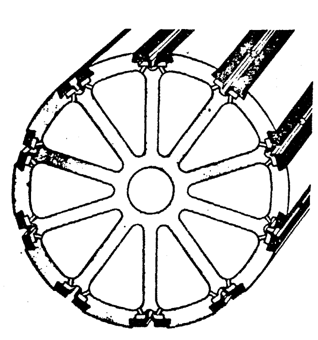
The man credited with inventing the nozzle process is Erwin-Willy Becker, a leader of the government-supported Karlsruhe Nuclear Research Center. A physical chemist, Becker published his first papers on the technology in the mid-1950's. He and his co-workers started up a 2-ton-per-year pilot plant in 1967 and in 1970 signed a "collaboration contract" with the large energy company of STEAG, AG in Essen, for further development work.

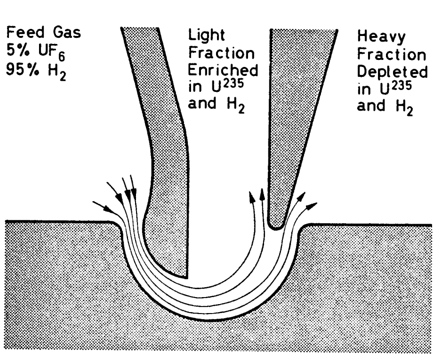
According to a paper presented by STEAG delegates to a London meeting of the British Nuclear Energy Society in March, a 5-year technology program began last year is aimed at testing prototype enrichment stages for a 2500-ton-per-year plant in 1977. Planning for a plant twice that size with 570 successive stages is under way.

STEAG representatives are saying little about their making plans beyond their declaration at the BNES meeting: "The offer is . . . made to the uranium producing countries to collaborate in partnership on utilizing the separation nozzle process for the enrichment of uranium."—R.G.

Schematic (below) shows flow of gas through a separation element in the Becker nozzle process. Multiple elements are arranged along a cylinder (right) to form one of many stages in the process train.







dicated by its insistence in the late 1960's that a clause be included in the NPT stating that the treaty shall be applied so as to

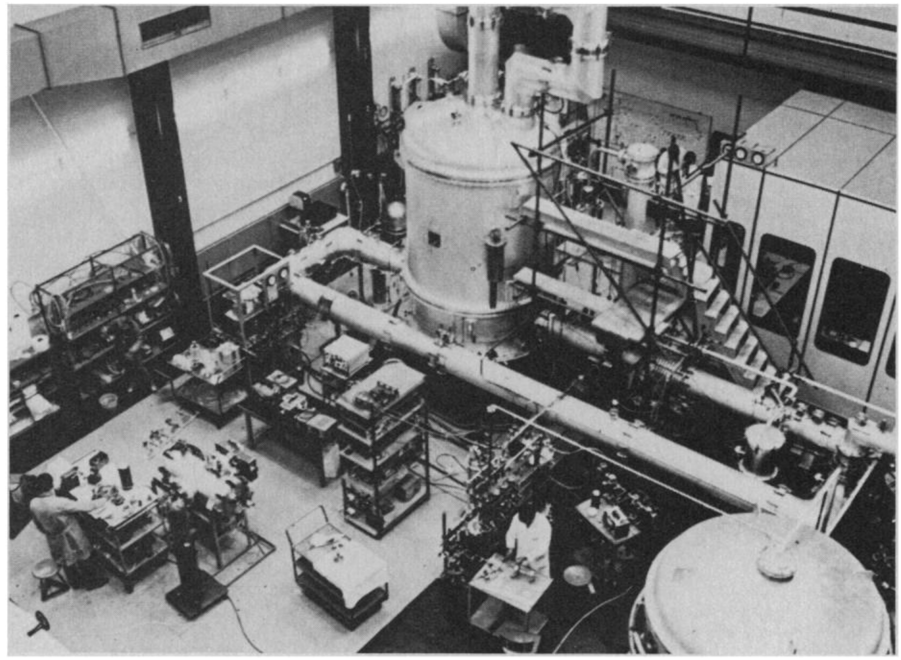
. . . avoid hampering the economic or technological development of the Parties or international cooperation in the field of peaceful nuclear activities, including the international exchange of nuclear material and equipment for the processing, use or production of nuclear material for peaceful purposes. . . .

The result of differing attitudes toward the export of nuclear technology is that U.S. companies competing for the Brazilian reactor market found themselves unable to match the breadth and attractiveness of the German offer.

Given the energy resources it has, a full suite of nuclear technology makes eminent sense from the Brazilian point of view. Brazil already imports three-fourths of its oil, its known resources are small, and demand is growing as the number of automobiles multiplies. On the other hand, Brazil's reserves of uranium are considerable and its deposits of thorium (which can be bred in reactors to form a new fissionable fuel, uranium-233) are second only to India's. Hydroelectric potential is also vast—an estimated 152,000 megawatts—but much of this power would have to be transmitted hundreds of miles to industrial centers like São Paulo, with consequent losses.

One alternative is to place electricity-intensive industries such as aluminum plants close to hydroelectric projects, but uranium enrichment offers another option. Putting an enrichment plant near a hydroelectric installation eliminates transmission losses to the plant and allows the energy—once converted to enriched uranium—to be trucked to nuclear plants near industrial centers.

Some U.S. enrichment experts believe this is precisely what Brazil has in mind, and they point to two hydroelectric projects as possible sites for a Brazilian enrichment facility. The first is the nearly completed Urubupungá project on the Parana River, west of São Paulo. One of the world's 10 largest hydro installations, Urubupungá's capacity is scheduled to grow by 1980 to 4600 megawatts, or more than twice the output of Hoover Dam. Further down the Parana River, along the Brazil-Paraguay border, construction is scheduled to start in August on the $4.2 billion Itaipú hydroelectric project designed to generate 12,000 megawatts. Half of this will go to Paraguay, which, with virtually no place to use it, will export the power back to Brazil. The size of a nozzle enrichment plant the Brazilian government has in mind has not been divulged, although the "reference size" being discussed by STEAG for a commercial plant in the early 1980's would consume 2500 megawatts and perform 5000 tons of separative work a year (this is a measure of enrichment capacity; U.S. gaseous diffusion plants are currently rated at 17,100 tons and consume 6000 megawatts at peak capacity).



Portion of a nozzle enrichment pilot plant at Karlsruhe.

If the pending nuclear agreement goes through it will represent a major breakthrough for Brazil, which has been frustrated since the early 1950's in its attempts to obtain uranium enrichment technology. In 1954, for example, before the Federal Republic gained its sovereignty, the United States squelched a German attempt to sell gas centrifuges to Brazil for a reported price of $80 million. The centrifuges were among those designed and built by Wilhelm Groth, a physical chemist who was instrumental in organizing the abortive German attempt to build an atomic bomb during World War II. The Brazilian government then turned to France in an attempt to obtain gaseous diffusion technology, again unsuccessfully. Finally, in 1958, Brazil did acquire three of Groth's centrifuges but evidently accomplished little with them. The machines, primitive by today's standards, were last heard from in 1964 when Brazilian researchers reported in Geneva that they had separated isotopes of argon.

In spite of these frustrations, Brazil's nuclear policy continued to drift toward a dependence on reactors requiring enriched uranium fuel (in contrast to that of Argentina, which has opted for natural uranium reactors much in the fashion of India).

Having gradually locked itself into light-water reactor technology Brazil then had a choice of depending on the United States or one of the other major industrial powers to supply enriched uranium—a dependence increasingly unpalatable in the mood of economic nationalism that currently pervades Latin America. Or Brazil could enrich its own uranium, if only someone would provide the know-how.

The latter alternative has doubtless become more appealing as the United States' ability to meet its foreign enrichment commitments in the 1980's has grown less certain. Moreover, nuclear exports come increasingly with "safeguard" strings attached that make it difficult for nations like Brazil to keep their explosives option open.

Safeguards Are Required

The Bonn government, as a party to the NPT, is obliged to sell such things as enrichment plants under safeguard controls, to ensure that the plant is used for "peaceful" purposes. But the NPT doesn't define the word "peaceful." And as the Indian test showed, there is room for disagreement as to whether it includes explosives.

Bonn could, of course, always ask for specific assurances from Brazil that its enrichment and reprocessing plant would only be used for making reactor fuel. But what worries U.S. arms control analysts is that no such assurances would apply to a second, third, or *n*th plant built entirely by Brazilian scientists and engineers who had thoroughly learned the workings of the first one.

"It's a very difficult problem," one U.S. proliferation expert says. "If it [the technology] is in the literature, how do you distinguish between what's transferred by license and what's transferred by textbook?"

As it happens, West Germany is transferring a great deal by "textbook." Nozzle enrichment technology has not been classified, and published technical papers on the subject go into far more detail than any available on gaseous diffusion or centrifuge technology. The firm of STEAG, in addition, takes the position that "local industry should . . . be permitted to participate in the project so as to obtain direct access to the technology."

To Latin American nations increasingly sensitive to "technological dependence" on the industrial powers, this is a powerful enticement.

And yet, as analysts of the proliferation problem point out, the path to nuclear self-sufficiency is also the path to a nuclear weapons capability. A small number of explosives requires only a small siphoning of material and talent from the main objective of electric power generation. Moreover, as one nation acquires the crucial equipment for self-sufficiency the incentive grows for its neighbors to follow suit. Both Brazil and Argentina, for example, have long dreamed of Latin American hegemony, and neither is believed willing to let the other realize its dream on the strength of nuclear superiority.

Some analysts, like Mason Willrich of the University of Virginia law school, have suggested that nuclear rivalries might be restrained by placing enrichment, reprocessing, and fuel fabrication plants under regional control. Britain, the Netherlands, and West Germany have taken a step in this direction with a tripartite agreement to build centrifuge enrichment plants.

Old rivalries are more durable in Latin America, however, and the outlook for such communal agreement there is poor. For the foreseeable future, nuclear machismo is likely to prevail.

—ROBERT GILLETTE

(A second article will discuss South Africa's uranium enrichment intentions.)

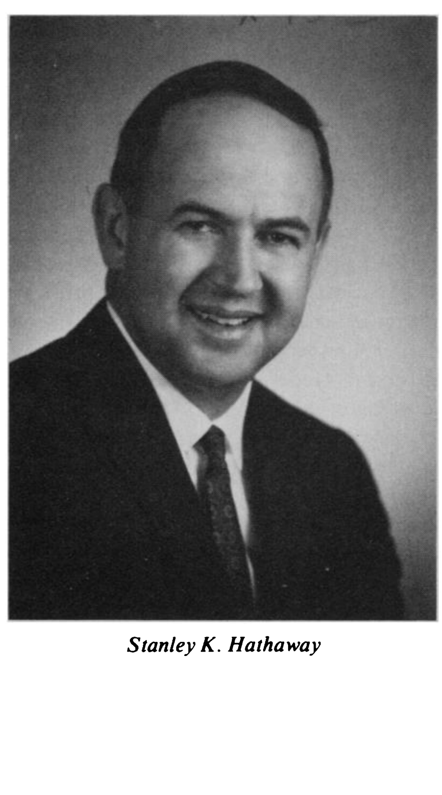
Stanley Hathaway: The Senate Looks at a Controversial Nominee

Taking the measure of a presidential nominee through questioning in a Senate hearing room is always a hit-or-miss process. But, as the result of such hearings, Stanley K. Hathaway is no longer so obscurely perceived as he was on first becoming President Ford's controversial choice for Secretary of the Interior. If environmentalists have been wrong to view Hathaway as an ogre, it appears that during his 8 years as governor of Wyoming he learned his lessons about resource management and environmental protection in a slow if not reluctant manner.

The Senate Interior Committee's 5 days of hearings on the Hathaway nomination, ending on 6 May, unfolded in a ritualistic manner. First, Hathaway was introduced and praised by members of the Wyoming congressional delegation. Later, an old-buddy network was brought into play when a panel of governors testified as to what a fine, able, and well-motivated fellow their former colleague was and is. The chairman of the National Governors Conference, Calvin Rampton of Utah, having hunted and fished with Hathaway, could certify that the nominee loves the land.

(Hathaway's outdoor-life credentials were reconfirmed last September when he made a kill early in Wyoming's annual One Shot Antelope Hunt, an event in which the governors of Colorado, South Dakota, and New Mexico also participated.)

Hathaway has been a truly popular figure in Wyoming, and the hearings reflected this. A succession of prominent people from his home state—such as officials of the Farm Bureau and the wool and stock growers associations—recommended him warmly to the Senate committee. Criticism of the nominee's record was left to spokesmen for environmental groups such as the Wyoming Outdoor Council, the Sierra Club, and the Environmental Defense Fund (EDF).



Stanley K. Hathaway

Although Hathaway's reputation back home is that of a man who can lose his temper when criticized, his manner before the Senate committee bespoke an unflappable cool. Moreover, this was in the face of sharp probing as to the honesty of a paper about his environmental record which had been prepared by some of his aides with plenty of puffery and some artful omissions. EDF had made a point-by-point analysis of the paper, and Senator Floyd K. Haskell (D-Colo.) made this EDF critique the basis of extensive questioning.

The confrontation between Hathaway and his environmental critics produced a substantial hearing record, and from it one can draw some conclusions about his performance as governor.

For one, it seems safe to say that Hathaway has not been indifferent to the need for environmental protection, as some have charged. But he has not generally tried to meet this need in an aggressive and far seeing manner. He often tended, especially during his first term (1967 to 1970), to push hard for industrial development even at the expense of his own administration's environmental protection programs. This was particularly evident in 1970 when he unsuccessfully sought to have new industry granted variances from air quality standards.

An uncritical bias in favor of industrial development also was plainly visible in 1968 when Hathaway and the state engineer tried to persuade the U.S. Bureau of Reclamation to lower the price of water from the Yellowtail Reservoir on the Big Horn River. The energy companies were already lining up to buy the water at the going rate. But Hathaway objected to the fact that the price was a few dollars higher per acre-foot than the price of water downstream in Montana, below Yellowtail and the associated hydropower turbines. Not