tions that "The gravest kind of danger stems from the illusion that, because certain data can be quantified and processed by a computer, therefore they must be more important than those which cannot be measured (*13*).

It is difficult to overemphasize the importance of a careful approach to SFE, from which much good can accrue. Careless SFE, concerned only with the narrow aspect of teaching effectiveness—if this indeed can be unequivocally established—will inhibit educational experimentation and development, particularly if SFE is used formally in the determination of salaries and promotions.

There is little doubt, however, that SFE in almost any form will become widely and rapidly accepted because it will permit academic administrators to shirk the responsibility of exercising judgment in the evaluation of teaching performance, and at the same time to use SFE as tangible proof that something is being done about improving teaching.

Conclusions

Desirable attributes of SFE can be vitiated by its premature utilization in a formal and quantitative sense. This is because it is possible to teach for a specific student evaluation, given a particular questionnaire. Consequently, because of the importance of SFE, the questionnaire must be designed to meet the expectations of the students, as well as the aspirations of the respective institutions. Indiscriminate use of SFE will increase the gap between first-rate and second-rate institutions—first-rate institutions will continue to attract more demanding students, a fact that will be reflected in SFE's, whereas second-rate institutions, in an effort to maintain levels of enrollment, may tend to formulate SFE's that emphasize popularity and mediocrity of education. Careful construction of the format of SFE, on the other hand, could do much toward increasing the quality of teaching, as well as the motivation of students and teachers, in many institutions.

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NEWS AND COMMENT

Uranium Enrichment: U.S. "One Ups" European Centrifuge Effort

The countries of Western Europe seem determined to end their dependence on the United States for a large part of the enriched uranium to fuel their nuclear reactors, but disagreement over the form that the European effort should take has produced a serious conflict of technical issues and national interests.

France has recently announced plans to build a \$1.4 billion new plant for uranium enrichment based on the expensive and slow but proved method—gaseous diffusion. Britain, the Netherlands, and West Germany, on the other hand, plan to build a plant based on a newer and more uncertain technology—the gas centrifuge. The advantage of the gas centrifuge method is that it requires far less electrical power and offers much more flexibility in the size of the plant.

As uncertainties about foreign oil supplies make nuclear power more and more appealing, the competition between diffusion and centrifuge methods is becoming a game with high stakes, not only for Europe but also for the United States. Three diffusion plants now easily supply all the U.S. demands for reactor fuel as well as foreign requirements, but new plants will soon be needed. In the next 2 years, the United States must decide whether to stick with the old technology or gamble with the new one.

At a recent press tour of the diffusion plant operated by the U.S. Atomic Energy Commission at Oak Ridge, Tennessee, AEC chairman Dixy Lee Ray told reporters that the United States has a substantial lead over Europe in the development of the gas centrifuge method. The tour marked the first time that reporters had ever been allowed to see the inside of a uranium enrichment plant, and Ray's remarks provided a clearer picture of the AEC's progress in developing gas centrifuge technology than had been publicly available. Because any country with the centrifuge technology could produce weapons-grade uranium in a small, easily concealed facility, the technology is closely guarded by the AEC as well as by Urenco, Ltd., the production arm of the collaborative British-Dutch-West German effort.

"Statements by Urenco officials would indicate that large European production plants would need hundreds of thousands of centrifuges," Ray said. "On the other hand, U.S. technology would require only tens of thousands of centrifuges for large-scale plants. It is this U.S. technology that is now being demonstrated in AEC facilities." Since both capital costs and operating costs of centrifuge enrichment plants are expected to be heavily dependent on the number of units needed, the statements of the AEC chairman indicate that the U.S. process will be many times cheaper.

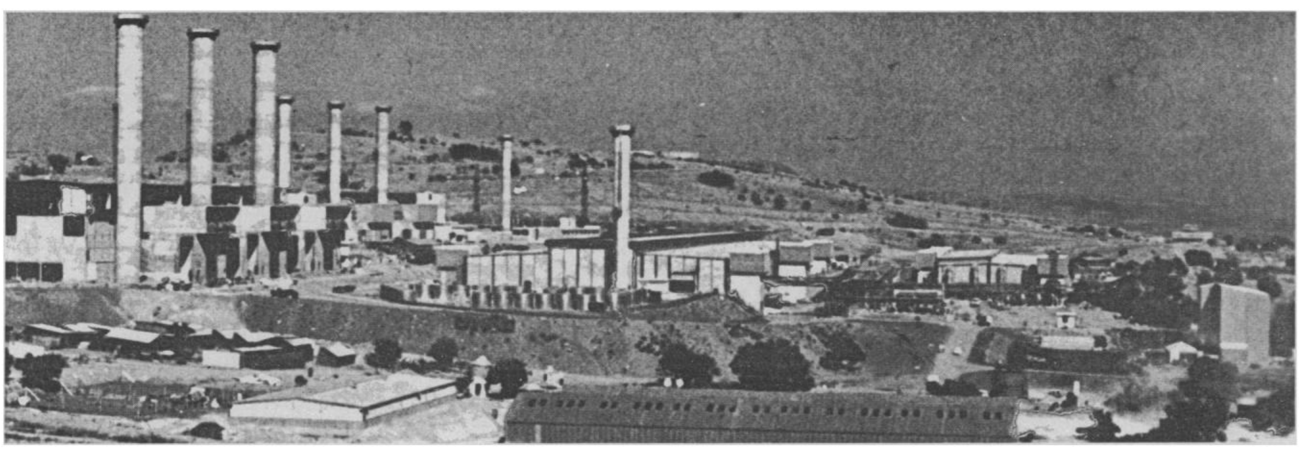
Urenco has announced plans to have two pilot plants operational by the end of 1976. They will have a combined capacity of 400 metric tons of separative work, or about 5 percent of the capacity of one of the large U.S. diffusion plants. In an apparently coordinated effort to "one up" Urenco, another AEC spokesman repeated Ray's statement 2 weeks later to the Joint Committee on Atomic Energy (JCAE), and said that the U.S. pilot plant now being constructed would have a greater capability than the one being built by Urenco in the Netherlands. The U.S. plant is being built at Oak Ridge at a cost of $27 million.

Members of the European community have clashed repeatedly over the question of how to build up their capacity for enriching uranium. Rather than make the large investment required for a diffusion plant, West Germany, the Netherlands, and Britain pioneered the work of perfecting the centrifuge technique during the 1950's and 1960's. France favored the diffusion technique, and built a plant at Pierrelatte, in southeastern France, where uranium for the French atomic bomb was produced. France began negotiating for Italian support for another diffusion plant in 1969 and the British-Dutch-German partnership was made official in 1971, but neither group appeared to be planning to have plants completed within the decade until the AEC raised prices drastically and stiffened contract terms last year.

Last April, France offered to supply West Germany with a very large order for uranium enrichment in 1980 from the French plant at Pierrelatte. It was an obvious move to corner a large share of the market just before the Urenco partners expected to be able to fill such an order themselves. Within days, the Urenco consortium responded by announcing that their own schedule would be advanced to be producing more than 2000 tons of separative work by 1980 and 8000 tons by 1985. France hurriedly drew together a consortium including Italy, Belgium, Spain, and Sweden, and by October formed Eurodif, the company that will build its plant. The large West German order was reportedly filled by the Soviet Union, which is also seeking uranium enrichment markets in Europe.

French officials say that the Eurodif plant will have a capacity of 9000 metric tons when it begins operation in 1979. Some observers doubt that the plant can be completed that soon, and in any case the capacity of both plants could easily exceed unmet demands. The French decision raises the specter of potentially disastrous competition between the two European suppliers in the 1980's. But in early March France announced that a site had been chosen for the plant at Tricastin, near Pierrelatte, and that four nuclear plants would soon be ordered to supply electrical power for the Eurodif facility, which will require 2400 megawatts.

Should European efforts to develop an independent capacity for uranium



South Africa's pilot plant for enriching uranium under construction at Valindaba.

South Africa's Process May Not Be So New After All

More than 3 years after the South African government first claimed it was developing an "entirely new principle" of uranium enrichment, the South African nuclear agency is said to have a pilot plant in production. The government is still being as cagey as ever about the nature of its "unique" and "competitive" process, but there is good reason now to believe that it's not quite so novel as the South Africans first claimed.

Informed speculation in the United States now leans toward the so-called "nozzle" process, an aerodynamic technique attributed originally to E. W. Becker and his co-workers in West Germany in the mid-1950's. In the basic process, a high-speed jet of uranium-bearing gas (such as uranium hexafluoride) is squirted through a nozzle into a low-pressure tank. The nozzle is aimed at a small "paring tube" on the opposite side of the tank which captures the central portion of the jet stream. Lighter atoms of uranium-235 stray to the outside of the stream, miss the paring tube, and thus are separated.

In another variant of the nozzle process, a stream of uranium-bearing gas collides with a stream of helium gas. Collisions between the helium molecules and uranium atoms do the separative work, sending the two different isotopes of uranium flying at two different angles.

According to testimony published recently by the congressional Joint Committee on Atomic Energy, relations appear to have been established between South African nuclear officials and a West German firm cooperating with Becker's laboratory. Karl P. Cohen, a General Electric scientist, told the JCAE last October that "we also know a lot of South Africans visited Becker's laboratory."—R.G.

enrichment falter, the United States plans to be well prepared to assist. The AEC estimates the potential foreign exchange from uranium enrichment to be between $50 billion and $70 billion, and 9 of the 12 new plants that it recommends the United States have ready by the end of the century are intended to supply foreign customers.

While the official statements about the U.S. advantage in centrifuge technology may be sobering to the Europeans, the news could not have come at a better time for some American interests. The Administration and the JCAE have for several years been trying to entice U.S. industries into taking over the government's role in uranium enrichment—particularly the task of building new plants. Planning for large plants requires up to 8 years, so the time for decision is imminent. At the Oak Ridge briefing, Ray said that the two large industrial combines* that have undertaken serious plans to build enrichment plants will make final decisions by July 1974 whether to go ahead or not. The news that the technology available from the AEC is ten times better than what potential European competitors have is certainly not going to be discouraging.

Perhaps because they were overwhelmed by being admitted at last to the giant plant where the stuff of bombs has been extracted for the last 20 years, most of the reporters at Oak Ridge overlooked Ray's statement about the technology that will probably be the key to uranium enrichment for the next 20 years. Methods employing a laser may eventually make the centrifuge and diffusion processes both obsolete, however, as reported here last week (*Science*, 22 March 1974).

The Oak Ridge diffusion plant is a huge, dark factory, almost empty of people, where there is no visible movement. Only the loud humming of compressors indicates that uranium hexafluoride is being continually pumped through gigantic "stages," which look like room-sized beer kegs but are filled with porous barriers made of a secret material. In each stage, the fissionable isotope of uranium, ^{235}U, diffuses through the barrier slightly faster than the nonfissionable isotope, ^{238}U. After raw uranium passes through a "cascade" of 1200 stages, it becomes enriched from the natural concentration, which is 0.7 percent ^{235}U, to the concentration useful for a light-water reactor, about 4 percent. To produce the high concentration needed for weapons, about 97 percent, uranium from the Oak Ridge plant is shipped to Portsmouth, Ohio, where it is passed through several thousand more stages.

In a centrifuge process, uranium hexafluoride gas is fed into a spinning chamber through a hole in the rotor shaft. The complex forces at work in the rapidly spinning system accelerate the heavier component, ^{238}U, outward to the walls and downward, and a flow pattern is set up. As the fissionable isotope, ^{235}U, circulates through the pattern, it is preferentially passed into an upper chamber through small holes near the rotor shaft. Scoops rotating in the upper chamber collect the enriched ^{235}U component and also generate enough pressure to carry it to the next stage. The centrifuge which the AEC used as the beginning of its research effort in 1960 has a chamber 3 inches in diameter and revolves at about 90,000 revolutions per minute.

The reason a centrifuge plant can be made much smaller than a diffusion plant is that very few stages are needed. According to Urenco director, Donald G. Avery, speaking before the JCAE last October, "A centrifuge cascade requires in the region of 10 to 12 stages to achieve the ^{235}U concentration required for a plant to produce nuclear fuel." This does not mean that a dozen centrifuges can produce fuel, because different numbers of centrifuges must be used in successive stages to achieve a graded flow capacity. But Avery said that a satisfactory cascade can be put together with as few as 100 centrifuges. The optimum number would certainly be larger, but even so a gas centrifuge production plant would certainly comprise many independent cascades. In contrast, a diffusion plant has only one cascade with the very large stages to achieve the maximum economy of scale. The flexibility of a centrifuge plant derives from the fact that it can be built up cascade by cascade, whereas a diffusion plant cannot produce enriched uranium until all the components of its single cascade are completed. Avery said that the Urenco partners have produced more than 8000 centrifuges.

The announcement that the AEC holds a substantial advantage in gas centrifuge technology is certain to have a chilling effect on the potential customers of Urenco, and could slow the trend for European utilities to buy their nuclear fuel at home. The AEC claim of superior technology may simply be a statement of justifiable pride in successful research. But it could also be a bargaining chip designed to keep European customers looking to America for uranium enrichment.

—WILLIAM D. METZ

* General Electric Company together with Exxon Nuclear Company, and Uranium Enrichment Associates, whose parent companies are Bechtel Corporation, Union Carbide, and Westinghouse.

Medical Education: Institute Puts a Price on Doctors' Heads

It costs $12,650 a year to educate a doctor. If you subtract from that sum the costs of research and patient care that can be considered essential to medical education, the cost comes down to $9700 a year, on the average. This is the price the Institute of Medicine of the National Academy of Sciences puts on doctors' heads.

The Association of American Medical Colleges (AAMC) puts it somewhat higher. According to the AAMC, the cost of medical education ranges between $16,000 and $26,000 a year, depending on where one goes to school.

These price tags are the products of studies that both organizations have been conducting on the cost of education. The institute's figures were released last month in its report *Costs of Education in the Health Professions*, which includes data on what it costs to educate persons in seven health professions in addition to medicine (see table).* The 18-month, $2.3-mil-

* This article deals primarily with the study's findings regarding the cost of medical education.