# France's All-out Nuclear Program Takes Shape

*If the experiment is successful, France may become a showcase for nuclear power*

At Creys-Malville on the bank of the River Rhone, some 30 miles east of Lyon in the province of Isère, the world's most advanced fast breeder reactor is coming into being. The 275-foot-high containment dome is already in place. Sometime this month, through a gaping hole left in its wall, a crane will hoist the massive steel cauldron built to hold the uranium-plutonium core of the reactor and the 3500 metric tons of liquid sodium needed to cool it. When the $2.5-billion reactor goes critical, scheduled for August 1983, France will have taken another major step toward the goal of making her uranium reserves a source of energy potentially equivalent to all the oil in Saudi Arabia.

Super-Phénix, as the Creys-Malville reactor is called, is the preeminent success symbol of an increasingly impressive technological enterprise, the French nuclear power program. By virtue of decisions taken long ago and steadily pursued while other nations dithered, France is emerging in the 1980's with what is certainly the most vigorous nuclear energy program in the world, and with an evident lead in several important aspects of nuclear technology.

The vitality of the French nuclear program is unmistakable. New nuclear power plants are now coming on stream at the rate of about one every 2 months, the maximum of French industrial capacity. Electricité de France, the national utility company, is investing 16 billion francs a year ($4 billion) in its policy of "tout nucleaire," that of building no more oil or coal fired plants but only nuclear.

In parallel with the reactors is a comprehensive program covering all parts of the nuclear power cycle, from the mining of uranium to the disposal of radioactive wastes. French technical competence has been demonstrated in the massive Eurodif uranium enrichment plant, which started production last year, in the La Hague reprocessing center, and in the development of breeder reactors, where France appears to exercise an increasingly commanding lead.

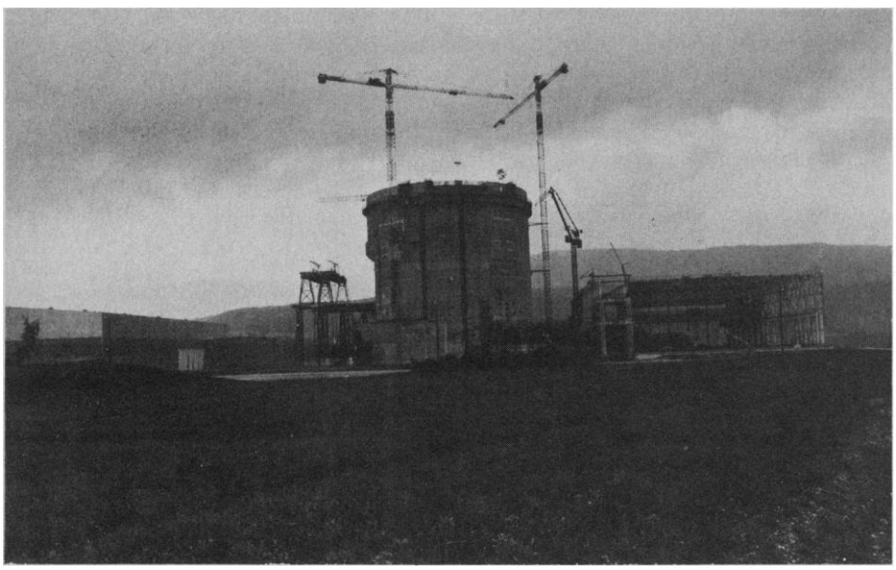
Energy independence is the necessity that drives this huge and ambitious undertaking. In the autumn of 1973, when the price of oil quadrupled, France found herself relying for 67 percent of her energy needs on imported oil. Quite apart from the political dependency so created, it was evident that the bills for oil were fast becoming unpayable.

The response was a decision to invest massively in France's one energy asset—a certain amount of uranium within her borders, plus a competence in nuclear technology born of a distinguished research tradition and a vigorous nuclear military program. Before the end of 1973, Electricité de France had decided that the existing nuclear power program would be expanded so that more than 60 percent of the nation's electricity would be of nuclear origin by 1985. A political consensus among France's four major parties, so far unshaken by environmental opposition, has enabled the program to be implemented without hesitation.

Eight years later, it is evident that the ambitious goal set in 1973 will be substantially, though not completely, attained. Nineteen reactors, with a capacity of 10,000 megawatts, are already in operation as of August 1980; by 1985, 49 nuclear reactors, with a total capacity of 40,000 megawatts, will supply 50 percent of France's electricity and 19 percent of her primary energy consumption. On 2 April this year, Minister of Industry André Giraud announced France's energy goals for 1990: nuclear's share of primary energy, still only 5 percent, is to rise to 30 percent by the end of the decade, with oil's contribution reduced to 30 percent by the same date.

"Just as at the races, the horses often emerge from round the turning post in a different order to that before, so France, following the confusion at the end of the 1970's, has suddenly found herself at the head of the pack of Western nuclear nations, both at the level of scientific research and at that of industrial accomplishments," writes Bertrand Goldschmidt, a longtime member of the French nuclear elite, in his recent book *Le Complexe Atomique*.* France's prominent position has made her nuclear energy program of increasing interest to other nations, especially now that all the main pieces of its infrastructure are in place and beginning to operate. Even a cursory tour of France's nuclear energy facilities, made by *Science* last month, makes evident the scale of the French undertaking.

The Super-Phénix reactor at Creys-



*The Creys-Malville fast breeder reactor under construction.*

*Fayard, Paris, 1980. Price 42 F.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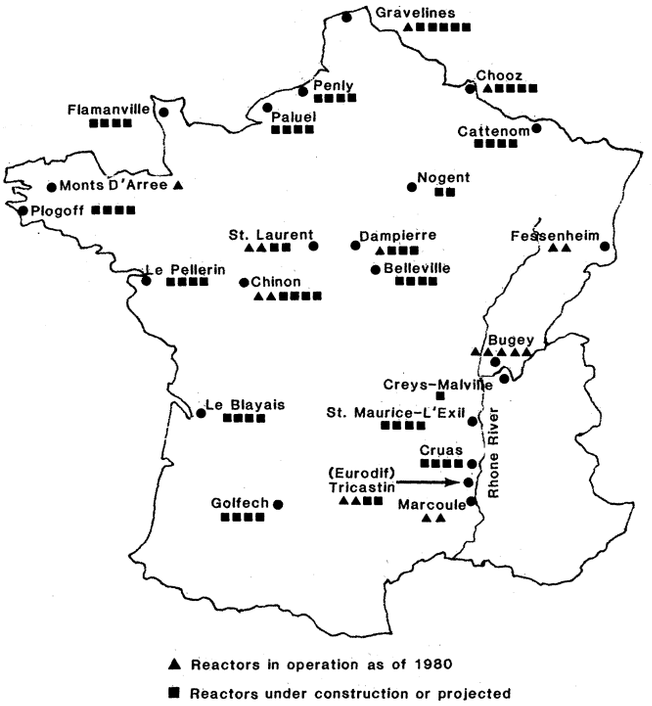
Malville, 1200 megawatts in capacity, will be the world's first commercial-size fast breeder when it comes into operation. Some 15 miles down the Rhone valley from Creys-Malville is the Bugey power station, where five nuclear reactors provide some 10 percent of France's electricity. The group is a symbol of a painful but clear-sighted decision. One of the reactors, the first to be built there, is a gas-graphite model of purely French design. The other four are pressurized water reactors built under license to the Westinghouse corporation of Pittsburgh. During the 1960's a bitter dispute arose between the Commissariat à l'Energie Atomique (CEA), France's powerful nuclear energy agency, and Electricité de France (EdF). CEA scientists favored the gas-graphite reactors, fueled by natural uranium, which they had developed originally to produce plutonium for France's military needs. EdF, however, wanted to standardize the future nuclear power program on light-water reactors, which cost only two-thirds as much to build and seemed slightly cheaper to operate. But because the reactors use enriched uranium, in which the United States had for long enjoyed a monopoly, the choice would mean buying an American design.

After considerable political maneuverings—at first the decision was referred to General de Gaulle, who in 1968 ruled in favor of the CEA, which he himself had founded in 1945—the EdF's position prevailed. The license fees owed to Westinghouse, which now amount to $200 million a year, were a small price to pay for an immediately available design already proven in worldwide markets. Everything has been done to profit from economies of scale. Matching EdF's size as a customer, the fragmented French nuclear industry was reorganized in the 1960's into a single large manufacturer, Framatome. The Westinghouse pressurized-water reactors (PWR's), virtually mass produced, are located usually four at a site for maximum standardization. The early models were of the 900-megawatt size, but EdF has recently switched to ordering 1300-megawatt reactors, a size in which it will be the world's most experienced operator before long.

In part because of these economies, in part because of a simpler licensing process, it takes from 6 to 7 years to build a reactor in France, compared with an average of 11 years in the United States. Though the cost of nuclear electricity, like everything else, is rising, nuclear stations are gaining a widening price advantage over oil and coal fired stations. According to EdF's calculations as of May 1980, the cost of nuclear electricity from its fleet of PWR's is 13.52 centimes per kilowatt-hour, compared with 24.79 for coal stations and 36.32 for oil stations.† In 1972, by contrast, all three forms of electricity cost much the same, from 4 to 6 centimes per kilowatt-hour.




*France's nuclear power program: reactors planned and in operation.*

Electricité de France's "tout nucleaire" policy has not been totally free of problems. The construction program is running about a year behind schedule, though the delay may not seem bad by international standards. A safety issue with the Framatome-made PWR's has cropped up in the affair of the "fissures," small cracks under the stainless steel cladding of the pressure vessel nozzles and the steam generator tube sheet. The problem was important in being generic: most of the PWR's so far made have the cracks, the cause of which was a new welding technique adopted by Framatome 5 years ago. But the cracks are all small, generally less than a centimeter in length and depth, and seem to be stable. Since they affect only the protective cladding, not the main plumbing, EdF has continued to put the affected reactors into operation while keeping close watch on the cracks and preparing remote control repair equipment should it be necessary.

The effect of the problem was magnified by maladroit public relations; although EdF had known about the cracks for 18 months, it allowed its unions to announce the cracks to the public in September last year, together with charges of a management cover-up. With the French public already sensitized to nuclear mishaps by the Three Mile Island accident (a PWR, but not of Westinghouse design), the news of the cracks created considerably less stir than might have been expected.

Electricité de France's other principal problem has been the often vigorous local opposition from the prospective neighbors of nuclear reactors. The recent announcement that those living near nuclear power stations will enjoy a 15 percent reduction in their electricity bills may or may not be persuasive but in any event underscores the government's sensitivity to the issue. Public opposition has been particularly vehement at the proposed nuclear site of Plogoff, a natural beauty spot on the westernmost tip of France, deep in Breton country. The 45 days of public hearings held there earlier this year turned into a daily battle, known as the "mass," which was celebrated by police and demonstrators from all over France. Despite the Bretons' manifest hostility, the three commissioners conducting the public inquiry recommended on 15 April that the nuclear station should proceed.

France's decision in 1970 to base her

†The figure of 13.52 centimes per kilowatt-hour for nuclear electricity is composed of 6.70 for investment costs, 2.55 for operating costs, and 4.27 for fuel. The investment costs are more than for oil or coal fired stations but the fuel costs are far less than both oil (now 26.56) and coal (14.25). The investment cost assumes a 20-year lifetime for the plants, with an average operating time of 5865 hours per year (67 percent), and includes a cost for decommissioning the plant. The fuel cost includes the mining of uranium and its preparation as oxide (54 percent), enrichment and manufacture of fuel elements (37 percent), and reprocessing and storage of wastes (9 percent).

nuclear future on PWR's entailed another far-reaching choice, that of ensuring a dependable supply of enriched uranium to fuel the reactors. The United States was offering enriched uranium at bargain prices, and the Soviet Union also had stocks for sale, invariably at 5 percent less than the going American price. Ignoring these siren voices, France determined to build her own uranium enrichment plant.

Down the Rhone valley from Bugey, about halfway between Lyon and Marseille, the realization of this decision has almost taken final shape. Started in 1972, the $5.5 billion plant is based on the technology of enrichment by gaseous diffusion which was developed by French scientists for the military enrichment plant at nearby Pierrelatte. The first stages in the Eurodif cascade came into production last year. When complete, in 1981, Eurodif will produce 10,800 tons of separative work units per year, about a quarter of the world production of enriched uranium, and enough to fuel one hundred 1000-megawatt reactors. Built on a gigantic scale, the plant itself requires four 930-megawatt nuclear reactors to fulfill its electrical needs.

Some 1400 stages constitute the cascade which rearranges the isotopic composition of natural uranium. Each stage has a compressor which pumps uranium—converted into gaseous form as uranium hexafluoride—through a fine porous filter. Because the uranium-235 penetrates the filter slightly more rapidly than does uranium-238, the gas at each stage becomes fractionally more enriched in the lighter isotope. The heaviness of the gas, and the speed with which it is pumped round the cascade, dictates pipes of massive thickness and equipped with shock absorbers. Natural uranium, containing 0.7 percent of the fissile uranium-235 isotope, enters the plant; uranium containing 3 percent of uranium-235, and depleted uranium are the outputs.

Eurodif, like Super-Phénix, is a European undertaking under French direction. Cogema, France's state-dominated nuclear materials company, owns 51 percent of Eurodif; the rest belongs to Italian, Belgian, Spanish, and Iranian interests.

A visible triumph of French technology, Eurodif is also a guarantee of independence. Never again will the United States be able to impose political or commercial conditions because of its monopoly of enriched uranium. "The Americans," says the CEA's Goldschmidt, "had started the war of reactor types. . . . They would effectively win

*(Continued on page 888)*

## Soviet Scientist Misses U.S. Parley

The 20th International Conference on High Energy Physics held recently at the University of Wisconsin attracted some 1200 scientists from around the world. A Soviet scientist who was to have had the most prestigious place on the program, however, did not show up.

No one is certain just what happened to Lev Okun, a leading Soviet scientist from the Moscow-based Institute of Theoretical and Experimental Physics. But his absence is believed to be politically inspired and has fueled speculation that the 1984 conference site, which was scheduled for the Soviet Union, might be moved to another country.

Prior to the conference, Okun had received permission from the Soviet authorities to attend. He had a visa and airline and hotel reservations, and had prepared notes for a speech that was to have been given on 23 July, the last day of the 6-day conference. When the 17 other members of the Soviet delegation arrived, however, they would say only that Okun had not boarded the airplane with them in Moscow.

Okun is a friend of dissident Soviet scientist Andrei Sakharov, but does not have a reputation for agitating Soviet authorities. According to conference organizers, Okun may at the last minute have been denied permission to travel because the conference had received several papers by Sakharov, a Nobel Peace Prize winner now living in exile in Gorky. Sakharov's papers, and an apology that some of his references were not complete because he is denied access to a library, had been smuggled out of the Soviet Union by persons connected with the International Zionist movement. Okun is believed to be Jewish.

Organizers of the conference sent a telegram, signed by 800 of the attending scientists, to the president of the Soviet Academy of Sciences protesting Okun's absence. Other actions are in the offing. At the 1978 annual conference, the sponsoring International Union of Pure and Applied Physics adopted a resolution that questioned whether the 1984 conference should be held in the Soviet Union if the absence of invited Soviet speakers continued at other meetings. In light of Okun's absence, conference organizers at the University of Wisconsin said that such a boycott was now becoming a distinct possibility. Lee Pondrom, a conference cochairman, noted that if the commission decided to change the 1984 site it would punish Soviet scientists who have no control over the situation. "But in some sense it would also punish the Soviet state," he said. "It is a situation similar to the Olympic boycott."

## Jordanian Accused of Plagiarism Quits Job

In the wake of accusations that he pirated 5 of his 60 published scientific papers, Elias A. K. Alsabti, 25, has resigned from an internal medicine residency program at the University of Virginia.

The resignation came on 2 July as administrators were convening a panel to investigate charges of plagiarism made by three groups of researchers (*Science*, 27 June). Since the resignation, journals that originally printed two of the papers have announced they will publish retractions. In a related development, a separate group of researchers in England has accused Alsabti of pirating an additional two papers—raising the number of papers under fire from five to seven.

Alsabti, who carries a Jordanian passport, went to the University of Virginia program in Roanoke after graduating in May 1980 from the American University of the Caribbean in Montserrat, the British West Indies, with an M.D. degree. While in Virginia, Alsabti denied having pirated the papers and threatened to sue anyone making such allegations (*Science*, 11 July). A few days later he resigned, having failed to answer tentative questions put forward by administrators at the University of Virginia concerning the charges of plagiarism. Officials said the panel would not pursue the matter further.

Retraction of one Alsabti paper is in the offing, according to Daniel Wierda, one of the researchers who had his work pirated by Alsabti. Wierda's paper appeared under his own name in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the combat and impose the light-water reactor, but at the same time would lose their trump card." In Eurodif, France feels she has finessed it.

If enrichment is one key to nuclear independence, the other, in the French view, is that of the breeder reactor. If used only to fuel light-water reactors, world uranium reserves will not last long. For France, Cogema controls about 100,000 tons of uranium in deposits in France and 140,000 tons abroad, chiefly in Niger and Gabon. But French consumption is at present 6000 tons a year, rising to an annual 10,000 tons in the 1990's, at which rate the present reserves will run out shortly after the year 2000. Light-water reactors, however, exploit only a fraction of the energy potential in uranium. Some 50 times more energy lies in the depleted uranium that is the by-product of the enrichment plant. The key to unlocking the energy is the breeder reactor, which converts the uranium-238 into plutonium, opening the way to the completely efficient use of uranium.

Some 10 miles down the Rhone from Eurodif, across the river from the ancient town of Orange, is the Marcoule atomic center and the Phénix breeder reactor. Phénix, which was put into operation on Bastille day, 1974, is the middle of a triad of breeder reactor prototypes that span a quarter-century of research. Rapsodie, at the nearby Cadarache research center, is its predecessor; the Super-Phénix at Creys-Malville is its successor. Each is a judiciously scaled up version of the last, the grand design being to attain a commercially viable reactor, preferably competitive in cost with the current PWR's.

Phénix has aroused the enthusiasm of nuclear engineers in France and abroad because of its almost faultless operating performance. The 250-megawatt reactor has validated several important aspects of breeder design, paving the way for the 1200-megawatt Super-Phénix. The costs of generating energy with the Super-Phénix are expected to be high—probably 24 centimes per kilowatt-hour, compared to 14 for the PWR's. When the commercial series of breeders starts, it is hoped that the cost can be reduced to 16 centimes per kilowatt-hour, partly by building the reactors in groups of four like the PWR's.

Essential to the operation of both the PWR's and later the breeder reactors is a viable system for reprocessing the spent fuel, a matter of removing the fission products and recycling the uranium and plutonium. Fuel from the PWR's will be reprocessed at the complex at La Hague, near Cherbourg, the only commercial-scale PWR reprocessing center at present in operation. Reprocessing is technically arduous, and carries the basic constraint of ensuring that the plutonium moving through the plant nowhere concentrates toward a critical mass.

*Minister of Industry André Giraud*

The main reprocessing plant at La Hague has had several successful runs since its debut in 1976, but has nowhere near reached its intended design capacity of handling 400 tons of spent fuel per year by 1980. Nonetheless, plans call for an increase of capacity to 1600 tons a year so as to handle fuel both from the French PWR fleet and from European and Japanese customers. In view of these plans, and a campaign by environmentalists to close down the La Hague plant, its operator Cogema was somewhat embarrassed when a fire broke out in the electrical substation on 15 April this year. The plant was back in operation within a week, with no radioactivity lost to the outside; nonetheless, the design of the substation was such that all main power was lost in the accident.

The final stage in the nuclear fuel cycle is the disposal of waste, a problem that is not regarded as insoluble in France. At the Marcoule center, a stone's throw from the Phénix reactor, is the world's first industrial-scale vitrification plant. Highly radioactive fission products, collected in liquid form by reprocessing plants, are first desiccated to a material that resembles freeze-dried coffee. In a continuous process, under remote control, the wastes are mixed with borosilicate powder, converted into molten glass, and poured into steel canisters. The canisters are at present stored in wells beneath the floor of the Marcoule vitrification plant, pending selection of a final storage site, probably in granite rock.

Because of its radioactivity, the glass can reach temperatures of 600°C at the center of the canisters, but French scientists state that it is thermally stable and hard to leach should it ever be exposed to water. Bellot, director of the Marcoule center, dismisses criticisms of the vitrification process as "marginal studies by people at American universities. This is not the only process, and we don't claim it is the best, but it is a commercial solution and it has attained its objectives," he says. The vitrification plant started operation in 1976, after many years of pilot studies, and has performed so well that it has already produced some 70 tons of glass, accounting for most of the backlog of high-level military waste stored at the site. A similar plant has been sold to Germany.

France's commitment to nuclear energy has solid political backing, but the program is far from being uncontroversial. On a local basis, as at Plogoff and now at Chooz, opposition is often vigorous. In July 1977 some 20,000 people attended a demonstration at Creys-Malville, in the course of which one person was killed and several wounded. But the local opposition has not so far made any real impression at a central level. All of France's four main political parties continue to support the nuclear program. The Gaullists and Giscardists have endorsed it without reservation, as has the Communist party. "The enemy of the workers is not nuclear power and science, but capitalists and management," declared a Communist deputy this June. There is a sentiment among the Socialist party to halt the breeder program, but the party otherwise is also pro-nuclear.

Critics often point out that parliament has not debated the nuclear program since 1975, and even then without a vote being taken. But the lack of debate is allied to a lack of any other good choices. "France has no viable alternative to nuclear power other than economic recession and dependence," states flatly Minister of Industry André Giraud.

Though the nuclear program is not cheap—it costs a total of $8 billion a year, with $40 billion already invested, according to one estimate—it has clear economic advantages. Besides the increasing price advantage of nuclear electricity, the implementation of the program creates jobs for more than 120,000 people. By 1985, nuclear energy should be providing the equivalent of 40 million

tons of oil a year, saving France some $10 billion in oil purchases even at today's prices. And France expects to earn a healthy income from the export of enriched uranium by Eurodif and of PWR's by Framatome.

The political standing of the program in France has also been helped by its achievements. The projects undertaken by French nuclear engineers have been successful, in the military as well as civilian fields. The management structure of the program owes much to Giraud, the present Minister of Industry. As head of the CEA from 1970 to 1978, Giraud shaped the major features of the present nuclear program, by pushing ahead with Eurodif, founding Cogema, healing the rift between EdF and CEA, and backing development of the fast breeder. French president Valèry Giscard d'Estaing, also an engineer by training, has given the program full support since taking office in 1974.

Continuity is the characteristic theme of the French nuclear power program. Beginning at least in 1970, a political and technical consensus as to its objectives has allowed France's program, perhaps alone of Western countries', a period of continuous and sustained development. The government has refused to be deflected from its nuclear goals either by internal opposition or by external pressures such as the nonproliferation policy launched by President Carter in 1976.

Is the French experiment of all-out commitment to nuclear power the one sure road to energy independence, as the government insists, or a gigantic economic and safety gamble which will bring the nation to disaster, as the program's critics predict? The ambitious program is only now beginning to assume its mature form, but the strengths already evident suggest that nuclear energy makes sense, at least for France.

—NICHOLAS WADE

# Malpractice Award Rattles Johns Hopkins

## *Former medical student wins $2-million verdict against his alma mater*

"I wouldn't have that boy's injury for $2 million, not even for $4 million," says Marvin Ellin, the trial lawyer some people call Mr. Malpractice of Baltimore, the one who on 26 June obtained for his client the largest medical malpractice award ever made by a jury in Maryland. The award—$2 million—was given in the Baltimore City Court to a 34-year-old ophthalmologist named James Lehninger.

The case is rare in that it involves one doctor suing another for malpractice. It is rare, too, to find so large a sum awarded for a less-than-devastating illness. (Lehninger fractured his hip on a ski slope 9 years ago, and complications arising from that accident will compel him to live with an artificial hip joint.) Most remarkable is the logic used to justify the award: Lehninger claimed he would lose $1.4 million in future income because his bad hip would force him to go into academic medicine rather than private practice.

The loser in the trial was the Johns Hopkins University Medical School, which runs the hospital and emergency room where the alleged malpractice occurred. The university is appealing the verdict on grounds that Maryland's 3-year statute of limitations bars action on a 9-year-old injury. Officials are unwilling to discuss details until after the appeal is tried, a proceeding which they say could begin next January.

Faculty members at Hopkins were shaken by the decision this summer, partly because they see in it the worst qualities of the lawyers' method of assuaging human injury, but also because it has drawn the school into a painful family dispute.

Lehninger was a medical student at Hopkins when the accident occurred. His most important witness against his alma mater was his father, Albert Lehninger, author of a widely used biochemistry text and for many years chairman of Hopkins' biochemistry department. The chief physician on the defense's side was Robert Robinson, an equally distinguished professor at Hopkins and former chairman of the orthopedics department. Both had retired from their chairmanships at the time of the trial. They remain on the faculty.

Faculty members do not want to be quoted, but they speak freely off the record of what they consider to be an outrageously generous award. Its size, they argue is out of proportion to the scale of injury, a windfall, as they see it, that plopped in Lehninger's lap because his skillful lawyer knew how to shake the tree.

They were particularly miffed by the economic rationale, which seemed to disparage academic medicine. Hopkins tends to see itself as a place where the academic elite is trained. Ellin brought to the trial an economic consultant named Manuel Smith who did some calculations for the jury. He computed Lehninger's probable working lifetime, his possible income as an ophthalmologist in private practice, and his probable income as an academic. The switch from private practice to academe, he figured, amounted to a loss of $1.4 million for Lehninger.

Ellin defends the claim eagerly, saying that $2 million is small compensation for his client's loss of quality of life. He points out that the jury did not stipulate how much of the total award was for economic loss and how much for mental anguish.

Because the bone in Lehninger's hip is deteriorating, Ellin says, Lehninger will have to have an artificial joint put in within a year. This will last for no more than 10 years before it becomes loose, when it will have to be replaced with a new joint which may last for no more than 5 years. After that, the bones will have to be fused, a procedure that leaves the patient walking with an unnatural, lurching gait. These problems, Ellin says, will make it impossible for Lehninger to develop a private practice. He will not be able to visit patients on the ward or remain standing during long operations. (Lehninger had hoped to be an ophthalmic surgeon.)

Furthermore, Ellin explains, Lehninger was a very "sports-minded" young doctor. He will no longer be able to run the 3 to 4 miles he ran daily while in school, nor will he be able to keep up his excellent game of tennis, nor will he swim competitively as he did before.


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