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111. This lecture is dedicated with affection and gratitude to Keith Porter, Philip Siekevitz, James Jamieson, Lucien Caro, Lewis Greene, Lars Ernster, David Sabatini, Colvin Redman, Jacopo Meldolesi, Gustav Dallner, Yutaka Tashiro, Tsuneo Omura, Gunter Blobel, Alan Tartakoff, David Castle, and George Scheele, my good colleagues and companions in the work carried out on the endoplasmic reticulum and secretory process.

**NEWS AND COMMENT**

# Discovery of Pulsars: A Graduate Student's Story

*Holmbury St. Mary, Surrey.* Perhaps the most dramatic scientific event of the last decade was the discovery in 1967 of the celestial objects known as pulsating radio stars or pulsars. The radioastronomy group at Cambridge, England, announced their detection of a wholly novel class of stars which beamed out pulses of radio waves with extraordinary rapidity and precision. The pulsars were soon determined to be neutron stars, the long-postulated embers of stellar evolution that astronomers had assumed were too faint ever to be detectable from Earth. And the public who followed these events enjoyed the frisson of learning that the Cambridge astronomers had for a time considered the signals might originate from another civilization, in token of which they had nicknamed the pulsars LGM stars, for "little green men."

Just how pulsars came to be discovered is a historically important case study in serendipity. The manner of the discovery is also of topical interest because of a dispute that has blown up over the award of last year's Nobel prize for physics. For the first time, the prize went to astronomers, and the Nobel committee honored Martin Ryle, leader of the Cambridge radioastronomy team, and his colleague Anthony Hewish, under whose supervision pulsars were discovered (see *Science*, 15 November 1974).

Hewish's citation was "for his decisive role in the discovery of pulsars," the qualification being there because, as Hewish has always acknowledged, the first finder of pulsars was his graduate student, Jocelyn Bell, now Burnell. Nobel prize committees have a reputation for doing their homework thoroughly, and if anyone thought the credit had been wrongly distributed, they kept their doubts to themselves, at least until recently. This March, after a lecture at McGill University, Montreal, English theoretical astronomer Fred Hoyle was reported to have described the award to Hewish as a scandal. According to *The Times* of London, Hoyle declared that Burnell's finding had been kept secret for 6 months while her directors " 'were busily pinching the discovery from the girl, or that was what it amounted to.' " But the victim of the alleged conspiracy disagreed. " 'It's a bit preposterous and he has overstated the case so as to be incorrect,' " she told *The Times*'s reporter.

There the matter might have rested, but a few days later Hoyle wrote from Rice University, Houston, where he was teaching at the time, to say that his views had been "only crudely represented." While not in fact repudiating any of the remarks attributed to him in the initial article, Hoyle proceeded to lay out his case more precisely. The actual discovery of pulsars, he said in his letter to *The Times* (published 8 April), seemed to have taken place in the 2-month period up to September 1967, but the finding was not published until February 1968, by which time it had accrued 5 authors including Hewish and Bell, together with four others who were cited for help in the discussions that led to the report. The publication consisted of two parts: the detection of the first pulsar, and a follow-up investigation. The second part of the process was guided by Hewish, but could have been done equally well by other observatories, Hoyle opined. The discovery of the signals by Burnell, and her finding that the source of the signals changed position with the stars, was what constituted the crucial step: "Once this step had been taken, nothing that happened from there on could have made any difference to the eventual outcome." Hoyle continued:

> There has been a tendency to misunderstand the magnitude of Miss Bell's achievement, because it sounds so simple—just to search and search through a great mass of records. The achievement came from a willingness to contemplate as a serious possibility a phenomenon that all past experience suggested was impossible. I have to go back in my mind to the discovery of radioactivity by Henri Becquerel for a comparable example of a scientific bolt from the blue.
>
> I would add that my criticism of the Nobel award was directed against the awards committee itself, not against Professor Hewish. It seems clear that the committee did not bother itself to understand what happened in this case.

It says nothing as to the merits or demerits of Hoyle's argument to note that his letter is part of a long series of dissensions which have made British astronomy a game quite unfit for children. The dispute has led, in one way or another, to Hoyle's resignation from his Cambridge Institute of Theoretical Astronomy (see *Science*, 2 June 1972) and to the resignation of Margaret Burbidge, now at the University of California, San Diego, from the directorship of the Royal Greenwich Observatory (see *Science*, 30 November 1973).

Hoyle's letter presented Hewish with the virtually no-win choice between saying nothing, thus seeming to have nothing to say, and defending his role in the discovery at Burnell's expense, with the risk of appearing somewhat ungallant. His decision was to reply with restraint (11 April), saying in effect that Burnell had been using his telescope, under his instructions, to make a sky survey which he had initiated. There were several problematical features of the pulsed source—a slight variability in its time of appearance, the possibility that

it was of human or alien origin—that had to be resolved under his direction. Although the source was first discovered in August, it was not until January 1968, the month before publication, that the necessary tests could be completed. Hewish concluded his account (which he had checked first with Burnell) by saying her performance as a graduate student was exemplary, but that it was "unjust to the painstaking efforts of others who have continued the sky survey to suggest that their work would have overlooked the first pulsars." Hewish gives a fuller account of his view of the discovery in his Nobel lecture, published in *Science* (13 June 1975).

In preface to Jocelyn Burnell's side of the story, it should be said that she has no disagreement with Hewish. She thinks that he deserves the prize, that she has been fairly treated, and that if he got more of the credit than she did, he also took more of a risk. Discovery of pulsars was an exciting event in her life—she was 24 at the time—but she is in no way mesmerized by it. She is working at present with a small team analyzing the data from a British x-ray satellite. Her laboratory, a rural outpost of London University, is situated in Holmbury St. Mary, a small hilltop village that overlooks the Surrey downs.

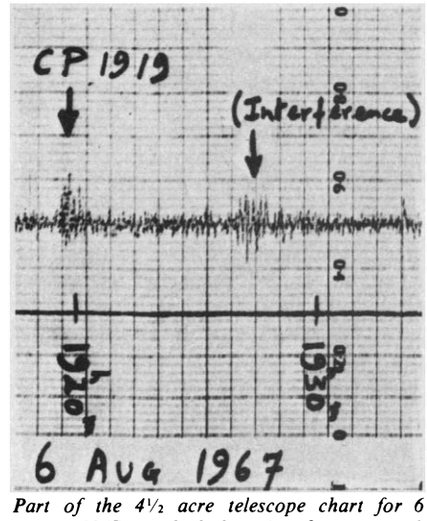
Burnell grew up almost literally in the shadow of astronomy, her father being the architect for the observatory at Armagh in Northern Ireland. From early on she wanted to be an astronomer but had to surmount the hurdles of a poor science education in high school—"The staff were not very well genned up on physics"—and a tough university course at Glasgow—"I was the only woman left in the physics class by the end of the first year."

With a bachelor's degree in physics, she was accepted as a Ph.D. student by the radioastronomy group at Cambridge in 1965. Graduate students are often jokingly referred to as slave labor. Burnell spent her first two years constructing the radiotelescope she was to operate and, though slight in stature, she could swing a 20-pound sledgehammer by the time she left Cambridge.

The instrument, known as the 4½ acre telescope because of the area covered by its 2000 dipoles, was designed to survey radio galaxies and to measure their angular diameter from the way the signals "twinkled"—an effect Hewish had discovered to be caused by the solar wind. The special design features that enabled the telescope to detect the twinkling were, as it happened, just what were needed to pick up the rapidly varying signals from the as yet unknown and unsought for pulsars.

Having helped build the telescope, it was Burnell's task singlehandedly to operate it and analyze its data until she had enough material for a thesis. The analysis was not much less arduous than the construction work. The telescope churned out 96 feet of 3-track paper every day. It took 4 days to cover the sky, so Burnell had about 400 feet of paper chart to analyze for each complete coverage of the sky. Her job was to scan the chart by eye, mapping the signals that were true twinkling radio scources and discarding those that came from man-made sources of interference, such as French television, aircraft altimeters, and pirate radio stations.

The temptation to cut corners on the analysis must have been considerable. The telescope was switched on in July 1967. By October, Burnell was 1000 feet of chart behind and by the end of November she was lagging a third of a mile. It was in October that she discovered the pulsar. Its signal, which she describes as "a bit of scruff," occupied about half an inch of the 400 feet of chart. "The first thing I noticed was that sometimes within the record there were signals that I could not quite classify. They weren't either twinkling or man-made interference. I began to remember that I had seen this particular bit of scruff before, and from the same part of the sky. It seemed to be keeping pace with 23 hours, 56 minutes, i.e. with the rotation of the stars."




*Part of the 4½ acre telescope chart for 6 August 1967, on which the pulsar first appeared. The blip to the right is an interference signal.* [*From* Science **188,** *1080 (1975)*]

Though much remained to be done, the nub of the discovery lay in that single instant of recognition. She remembered she had seen the same "bit of scruff" at roughly the same time of day in previous charts, and she found on measurement that it was keeping sidereal, not terrestrial, time. (The sidereal day, because of the earth's revolution about the sun, is 4 minutes shorter than the terrestrial day.) In Burnell's words: "When it clicked that I had seen it before I did a double click, I remembered I had seen it from the same part of the sky before. This bit of scruff was something I didn't completely understand—my brain just hung on to it and I remembered I had seen it before."

Looking back through the records, she found the first time the scruff had appeared was on 6 August. She discussed the signals with Hewish, and they jointly decided to look at them on the observatory's fast recorder, then occupied with another task, so as to get a clearer picture of the signal's structure. The recorder became available

Photo by Roger Robinson

in mid-November, and Burnell went out to the telescope at the time of day the source was passing through the beam. But for several weeks nothing happened. The signal, at all times variable, failed to show at all. "Hewish was thinking at that stage that it was a flare star and that we had missed it," says Burnell. "Finally one day I managed to catch it, and I got a series of pulses coming out of the recorder. They were almost exactly 1⅓ seconds apart. That is a very sort of man-made period. Tony Hewish had left the recording to me. I phoned him up to tell him about the pulses and he said, 'Oh that settles it, it must be man-made.' "

# Briefing

## Land Use Legislation Defeated in Committee

Two major environmental items on the congressional agenda this year have been the strip mining and land use bills. The strip mining bill was lost in June when the House of Representatives failed to override a presidential veto. Now the land use bill has been lost as the result of a vote taken in the House Interior Committee on 15 July.

The committee voted 23 to 19 not to report the bill to the full house, thus probably wiping it from the agenda for this Congress. The bill's sponsor, Representative Morris Udall (D-Ariz.), was bitter in his comment on the committee action: "It was the predictable result of the erosion of support which began last year when then-President Nixon suddenly withdrew Administration backing of the bill, giving credence to a well-orchestrated campaign of distortion led by the U.S. Chamber of Commerce."

The product of many compromises, the land use bill would have authorized $500 million in grants over the next 6 years to encourage the states to set up mechanisms for controlling land use in "critical" areas, such as floodplains or ecologically sensitive swamplands, and for regulating critical uses, such as large-scale industrial or residential development. Despite its emphasis on state and local responsibility for land use regulation, the bill seems to have become a detested symbol of governmental intervention for conservative groups such as the Chamber of Commerce, the Farm Bureau, and the Liberty Lobby.

The bill would not have been defeated in committee had several members who voted with Udall on a critical procedural motion in May not voted against the bill in this latest test. One of them was Representative Roy Taylor (D-N.C.), who frankly attributed his negative vote not to a new perception of the bill's merits but to exceptionally strong "grass roots opposition" within his district. Another who voted to keep the bill alive in May but to kill it in July was Representative Allan T. Howe (D-Utah). According to one of his aides, Howe had come to question the merits of the bill and even to doubt assurances that the program to be established would always be all carrot and no stick.

But, again, a possibly compelling consideration was the fierce opposition to the bill among Howe's constituents. "It has been an issue on which we have received more mail than on Vietnam, Richard Nixon, or amnesty [for draft-evaders]," the aide said. "It ranks with gun control and gas rationing as a matter of controversy in our district."

Udall predicts that "the victory of land use planning opponents will be short-lived" because of the public concern that will be aroused by a continuing degradation of land resources by uncontrolled development. But, if land use measures are indeed taking on the symbolic overtones associated with such perennial losers as gun control bills, things may really have to get bad before Congress brings itself to act. For the next few years, at any rate, the states that have been showing a growing interest in land use control will remain largely on their own.—L.J.C.

## ACDA Scotches Rumors of Argentine Nuclear Theft

Has Argentina purloined some of its own plutonium? Rumors that the Argentine government attempted to evade international safeguard controls to divert as much as 50 kilograms of plutonium from its new power reactor at Atucha, near Buenos Aires, have circulated through Washington for several weeks, prompting an unusual denial in late July by the State Department's Arms Control and Disarmament Agency. According to an ACDA spokesman, "The U.S. government has no reason to believe that Argentina has sought to divert nuclear materials in violation of International Atomic Energy Agency [IAEA] safeguards."

The rumor, based on an intelligence report of uncertain origin, caused a considerable stir in official Washington, coming as it did at the height of concern over West Germany's agreement to sell nuclear fuel technology to Brazil, Argentina's chief political competitor.

The rumor was, moreover, at least marginally plausible. Some State Department officials are convinced that both the Brazilian and Argentine governments have opted to develop nuclear explosives as the necessary nuclear fuel technology becomes available. Eighteen months ago Argentina became the first Latin American nation to operate a nuclear power reactor, a 320-megawatt German model fueled with natural uranium—a design that permits unloading of irradiated fuel containing plutonium without shutting the reactor down. Argentina also possesses a small fuel reprocessing plant for extracting the plutonium.

Thus the putative report of a diversion found fertile ground in Washington. Sources say, however, that investigation by the IAEA found it to be "substantially in error" and that Argentina's small stockpile of plutonium—ostensibly accumulated for fast-neutron reactor research—was all present and accounted for. What's more, the diversion of 50 kilograms of plutonium (enough for at least five explosives) would have required reprocessing some 40 to 50 tons of spent fuel, far exceeding the reported 200-kilogram annual capacity of Argentina's plant. The plant, at last report, was in a dismantled state awaiting expansion.—R.G.

## United States Neglects Civilian R & D

The United States puts too many research dollars into defense and space and too few into the civilian R & D that undergirds its commercial prosperity. If a halt is to be put to the relative industrial decline of the United States compared with Europe and Japan, government support for research must be shifted away from the pattern dictated

Hewish came out to the observatory the next day to watch Burnell make another fast recording. The signal was quite strong that day and she was able to produce a nice train of pulses for her supervisor's satisfaction. Hewish then went through the records and confirmed that the source was keeping sidereal time.

"We had terrible trouble trying to sort out that conundrum," Burnell recalls. The problem was that the fastest variable star then known had a period of one third of a day, and no one could conceive of a star with a period of 1⅓ seconds. But the source couldn't be man-made either be-



by the Cold War and toward the emerging civilian priorities of economic growth, export competitiveness, and social welfare.

This is the argument of a report* prepared for the Joint Economic Committee by Robert Gilpin, professor of public and international affairs at Princeton. Gilpin, who is a political scientist, not an economist, by background, wrote the report at the request of committee chairman Senator Lloyd M. Bentsen (D-Tex.). His message is not wholly new but, in the continuing absence of a national science policy, bears repetition.

The major capital stock of an industrially advanced nation, according to economist Simon Kuznets, "is not its physical equipment; it is the body of knowledge amassed from the tested findings of empirical science and the capacity and training of its population to use this knowledge effectively." According to Gilpin, the United States has invested an "inordinate proportion" of this stock in a few areas of big science and technology, and a "much higher level of performance" is required in civilian-industrial R & D if the country is to meet intensified international competition and resolve its domestic problems.

Gilpin does not say how much higher the performance level should be and, pleading the ignorance of economists on this point, offers only the most general of ideas on how the government should go about encouraging industrial innovation. He believes that with large scale projects the government should support general basic research which reduces the risk for commercial developers; but the government should not attempt to usurp the entrepreneur's role by trying to bring a product to market—as the Energy Research and Development Administration is doing with the breeder reactor.

The best way to encourage innovation is by "demand-pull," not "technology-push": in other words by creating the market conditions that stimulate innovation rather than by creating new technology and hoping that a market will materialize for it. Most of the technology incentive programs run by the National Science Foundation and other agencies have in fact followed the technology-push strategy, which may be why they have not yet fulfilled the expectations of their creators.

The Japanese have been highly successful in linking technology with economic policy whereas the British "have on the whole made very poor use of their rich scientific and technological resources." In Gilpin's view, American policies have been closer to the British than to the Japanese model. The British government, like the American, has overinvested in a few narrow sectors of high technology and has assumed an entrepreneurial role for which governments are poorly suited.

Japanese methods, which include denial of credit to backward industries, are too high handed to be acceptable in the United States. Nevertheless, Gilpin advocates firm action in establishing priorities among the various scientific fields. Though his analysis is blunted by its lack of specific remedies, it has the unusual advantage of admitting to ignorance where admission is due.

—N.W.

*Technology, Economic Growth, and International Competitiveness. 88 pp. Obtainable from the Government Printing Office, Washington, D.C. 20402, $1.10.

## CEQ Relaxes Stand on Predator Poisoning—Biter Beware

The Council on Environmental Quality (CEQ) has announced that the government will permit a new experimental use of sodium cyanide to kill coyotes that attack sheep. The latest decision is a modification of a 1972 executive order that bans predator poisoning on public lands except under emergency conditions.

Coyotes are responsible for the death of 3 to 5 percent of sheep herds in the West (25 percent in some areas), said CEQ head Russell Peterson. Sheepherds find the losses hard to bear, since the sheep industry has been steadily declining since the 1940's.

The simplicity and restraint that characterizes the new idea perhaps explains why it wasn't thought of before. Most coyotes don't like eating sheep (rabbits are their staple), but a few love them, and will attack again and again. They prefer lambs, preferably tethered, and they attack by lunging at the neck. So a poisonous collar—a necklace of sodium cyanide capsules—has been devised. A few lambs will be tethered at the edge of their herd and fitted with the collar. A passing coyote with an eye for sheep will leap at the animal's neck, his teeth will puncture a cyanide pellet, the poison will squirt in his mouth, and voilà! he will drop dead. Peterson says tests in large pens show that this works, and furthermore the lamb generally escapes unharmed. The project has virtues ecologically not only because of its selectivity but because carrion eaters happening upon the dead coyote will not be poisoned by eating the flesh.

Peterson, in answer to a question, said it was possible the technique could have an aversive conditioning effect on whole populations of coyotes—one day, perhaps, breeding an antisheep attitude into the subconscious of the race, as it were.

Peterson said if the $3-million, 1-year project works as hoped, other coyote-killing methods might be outlawed. These include shooting them from helicopters and planting pieces of meat attached to M-44 sodium cyanide guns in coyote territory. The latter method has resulted in deaths among several species of animals and does not have any special appeal for sheep-loving coyotes.

Defenders of Wildlife, a Washington group that fought for the 1972 poison ban, has criticized the recent action on the grounds that it opens loopholes for indiscriminate poisoning programs to resume. The government argues that relaxing the order to allow experimental programs will permit development of more effective and environmentally sound means of predator damage control.—C.H.

cause it reappeared with each revolution of the stars, not with each rotation of the earth. Could it be radar signals bouncing off the moon, or a satellite in a peculiar orbit? That didn't fit. Burnell and Hewish then realized that the only people on Earth who keep the 23 hour, 56 minute schedules of sidereal time were other astronomers.

"Hewish wrote round to all other observatories asking them if they had had any such program going since October. All wrote back saying, 'No we haven't.' " The next idea was the little green men thesis. "Although they don't take it very seriously," remarks Burnell, "radioastronomers are aware that they would probably be the first people to come into contact with other civilizations. So Hewish timed the pulses to see if there was a Doppler shift." The rationale was that the aliens would presumably be resident on a planet, and the planet's orbital movement around its sun would produce a bunching of the pulses as it moved toward the earth and a spacing out of pulses as it moved away.

This moment in the investigation, when the Cambridge radioastronomy group was seriously considering that the pulses might be signals from another civilization, is described with notable terseness and understatement in the logbook that Burnell kept at the time. Her entry for 19 December 1967 refers to a radio "source"—source in quotation marks because Hewish still doubted that it was genuine—but under the remarkably prescient heading "Belisha beacon." A Belisha beacon is the regularly flashing orange globe that warns motorists in England of a pedestrian crossing; Burnell gave the source this private nickname—the rest of the group called it the LGM star—*before* she had even detected the pulsations on the fast recorder. Her logbook reads as follows:

> *Belisha beacon.* There exists a radio "source" which keeps constant RA. [right ascension] to within $5^s$ and constant dec [declination] to $1/2°$, which has been observed over 4½ months. It passes through the beam of the aerial at the same rate and in the same direction as any other source. It consists of pulses at equal intervals (~ 1.3 secs.). . . . This "source" is very close to the Galactic plane ($b^{II} = 4°$). The one mile telescope [one of Ryle's big radiotelescopes] has had various attempts to find it, but has not seen it so far. We are working on the Doppler shift of the pulses to see whether the source is stationary or moving round a sun. There is no 4C source [the Cambridge catalog of radio sources] with the same coordinates, nor any other source that we know of. . . .

As it happened, Hewish found no Doppler shift except that due to the motion of the earth, which ruled out any planet or little green men or alien communications system. At the same time, or slightly before, Burnell took the step which more or less settled the nature of the "source." She discovered a second "source." The day before she left Cambridge for her Christmas holiday, "I was working in the evening analyzing chart. I saw something which looked remarkably like the bits of scruff we had been working with. This was in a bit of sky that wasn't very easy for the telescope to look at, but there was enough to confirm that there had been scruff.

"That particular bit of sky was due to go through the beam at 1 a.m. It was a very cold night, and the telescope doesn't perform very well in cold weather. I breathed hot air on it, I kicked and swore at it, and I got it to work for just 5 minutes. It was the right 5 minutes, and at the right setting. The source gave a train of pulses, but with a different period, of about 1¼ seconds."

Did she phone Hewish to tell him of the second discovery? "Not at 3 o'clock in the morning, oh no. I dumped the recording on his desk and left for my holiday. I don't think he really believed that one. But he kindly kept the telescope running and the inkwells full of ink while I was away."

### Little Green Men Ruled Out

Hewish himself did a recording in the middle of the night in mid-January and confirmed the second source of pulses. "That removed the worry about little green men, since there wouldn't be two lots signaling us at different frequencies," says Burnell. "So obviously we were dealing with some sort of very rapid star. I threw up another two sometime in January."

Those were the last two pulsars she discovered because by mid-January it was time to start writing up her Ph.D. thesis, to which pulsars appeared as an appendix. The existence of the stars, which hitherto had been kept a closely guarded secret, was announced by Hewish at a seminar in Cambridge, and to a wider audience by the paper in *Nature* (24 February 1968). Burnell's name was second on the list of authors, followed by those of three other members of the radioastronomy group who helped with various stages of the follow-up study. Following custom, there was no indication of who had contributed what.

Publication caused a sensation, but Burnell was busy trying to get her Ph.D. thesis written up and looking for a job in the south of England, where her fiancé, a government employee, was then working. She joined a group doing gamma ray astronomy at Southampton University and taught there for 5 years, but had poor scientific data to work with. A year ago she came to the laboratory at Holmbury St. Mary, where she works half time—afternoons are spent at home looking after her 2-year-old son. Her group has obtained excellent data from their x-ray satellite. Earlier this year they discovered a transient x-ray source with the interesting period of 6¼ minutes. Recently Burnell and her team discovered a new transient source near the Crab nebula with a period of about 1½ minutes.

Looking back on pulsars, Burnell feels that the hardest part about the discovery was simply spotting the signals amid each 400 feet of chart paper. A second danger point was that the signals might have been dismissed as man-made interference. She has heard rumors that another radioastronomer in Britain noticed pulsar signals on his charts before her discovery but failed to follow them up. She rejects the implication in Hoyle's letter that she had to pursue her investigation of the anomalous signals in the teeth of terrible opposition, which, she says, was certainly not the case. Yet she seems to have been less ready than her elders to doubt that her "bit of scruff" was a real signal from a real star. "I certainly joined in the business of trying to explain it away as wholeheartedly as everyone else," she says, "I think I probably suspended belief." But, even if suspended, the belief that her "Belisha beacon" was a genuine star was always there. "My background in astronomy wasn't as good as Hewish's and I didn't appreciate all the risks. He ruled it out as a star—muggins [herself] didn't realize why it could not have been a star. I continued to think it was a star until someone pointed out to me how fast [the rate of pulsation] was."

Should Burnell have received a share of the Nobel prize for pulsars? The question raises some tangled issues. For one thing, there is a general expectation among scientists that the Nobel prize should not be awarded for a single chance discovery, but should go to the individual with a long career of successful contributions. Nobel's will, however, says nothing about careers: he stipulated simply that the award should go to "the person who shall have made the most important discovery or invention within the field of physics."

Pulsars may not now seem as tremendously interesting as when they were less well understood, but they are still sufficiently remarkable objects, many astronomers would say, to merit a Nobel prize for their discoverer, assuming that the prize should be given for a single discovery. But how should the credit for that discovery be distributed? Nuclear physicists employ trained scanners to analyze photographs of particle tracks. No one has suggested that the scanners should receive a Nobel prize when they pick up a new particle. But there are differences between this case and that of pulsars. The discovery of pulsars was neither planned nor predicted: as Hewish says in his Nobel lecture, he stumbled upon them.

Nor does Burnell's contribution seem to everyone to have been as routine as a hired scanner's. Hewish considers that it was. "Jocelyn was a jolly good girl but she was just doing her job. She noticed this source was doing this thing. If she hadn't noticed it, it would have been negligent," he told *Science*. Cornell theoretical astronomer Thomas Gold disagrees. Gold, who first came up with the accepted theoretical explanation of pulsars, points out that Burnell, unlike a photo scanner, understood the basis of what she was doing and, moreover, had not been told to look for pulsars. "She was told to plot scintillating radio sources, but she noted and pursued in her own way a different kind of signal," Gold remarks.

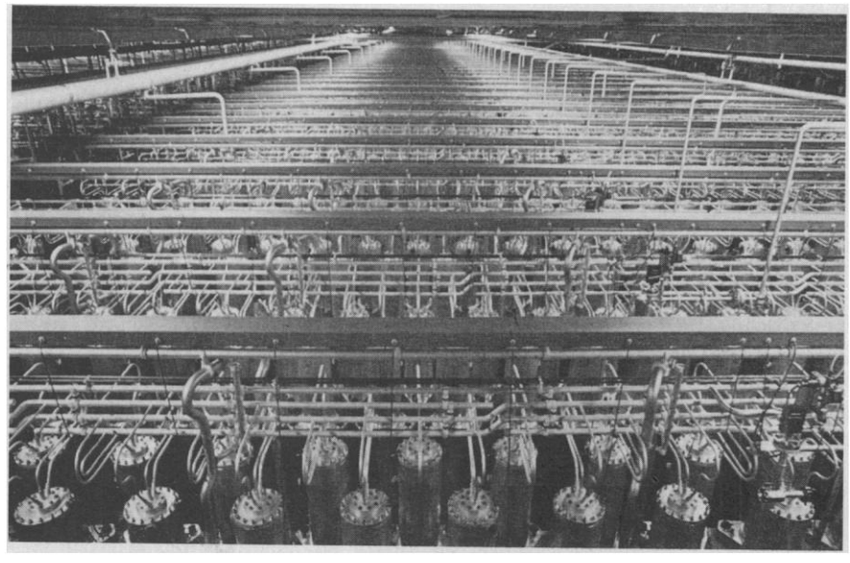
Hewish's point is that he had instructed Burnell to plot all signals on a graph; the genuine radio sources would reappear from day to day, interference signals would not. From this routine, pulsars would emerge automatically. The signal "didn't look very different in the record from anything else we were plotting. It's an absolute certainty that [if Burnell had not done so] someone else would have picked it up," says Hewish.

"I would not say it was 100 percent automatic, but I would think that it is reasonably likely that that telescope would have discovered pulsars sooner or later," replies

# Problems with the Enrichment Program

While the Ford Administration is encouraging U.S. industry to get into the business of enriching uranium for nuclear reactors, the start-up of the first government pilot plant to test the centrifuge enrichment method has been delayed at least a year, to July 1976. Officials of the Energy Research and Development Administration (ERDA) cite inflation and modifications resulting from a dramatic centrifuge failure in October 1973 as the reasons for the delay. The pilot plant, being built at the Oak Ridge, Tennessee, laboratory* of ERDA is now expected to cost $31.8 million.

The 1973 accident apparently damaged much of an Oak Ridge test facility. When the ultrahigh-speed rotor inside one centrifuge disintegrated, that machine ripped loose from its mountings and dislodged two others. Many additional centrifuges in the facility were damaged by the shocks that propagated through the building. Redesign of the pilot plant is focused on strengthening the centrifuge mountings.



*German centrifuge pilot plant at Almelo, Netherlands.*

With the projected starting date for the pilot plant moved back to 1976, the U.S. program appears to be lagging well behind the program of the British–Dutch–West German combine that began operating a pilot plant at Almelo, Netherlands, in 1971. The European centrifuge combine is now operating three pilot plants, and is building two commercial demonstration plants at Almelo and Capenhurst, England, that are due to begin initial operations next year.

Until the first U.S. pilot plant is working, uncertainty about the centrifuge process may discourage companies from making the $2 billion commitment necessary to construct a full-scale plant. Last year the Nixon Administration failed in a bid to attract industrial participants to build new enrichment plants, and three major industrial firms, General Electric, Westinghouse, and Union Carbide, have signaled their lack of interest in building future plants by dropping out of the ERDA plan for sharing information on enrichment technology. Boeing and General Atomic have joined the arrangement for sharing the classified information about enrichment, and presumably they, along with the firms that have shown continuing interest—Electro-Nucleonics, Goodyear, Exxon Nuclear, and Bechtel—are the most likely bidders for a centrifuge plant.

The bill proposed by President Ford would authorize ERDA to grant contracts for several private centrifuge plants, as well as one plant using the older method of enrichment—gaseous diffusion.

Goodyear and Bechtel, as partners in Uranium Enrichment Associates, are the only U.S. firms seriously considering a plant using the time-tested but energy-inefficient method of gaseous diffusion. Diffusion plants, in which gaseous uranium hexafluoride is forced under pressure through a porous barrier, are estimated to use ten times as much energy as centrifuge plants.

Besides the reliability of the U.S. centrifuge process, another factor members of the corporate boards would like to understand better is the role that lasers will play. Laser enrichment methods are improving rapidly, and could conceivably leapfrog over the centrifuge process. Under considerable pressure from the companies participating in the information access plan, ERDA officials gave a briefing on the status of the closely guarded laser technology on 6 June in Livermore, California.—W.D.M.

*The famous Tennessee laboratory, briefly renamed the Holifield National Laboratory through legislation quietly effected by friends of the retired California congressman, Chet Holifield, is now being rechristened the Oak Ridge National Laboratory by a bill recently passed in the House.

Burnell. In the early stages of operation, however, the routine for analyzing the recordings had not been fully worked out. The "bit of scruff" looked different both from the scintillating sources and the interference signals she had been told to plot. Though she cannot remember definitely, she "suspects" that she did not record it on the graph. Asked about this point, Hewish says he does not remember if Burnell plotted the pulsar signals on the graph and would trust her memory of what happened; he does remember, however, that the first time she mentioned the signal she showed him the direct recording from the telescope. Thus it would seem that Burnell's discovery of the repeating nature of the signals was a feat of unaided memory and observation, not the result of following a preset routine; in turning up the pulsars she was going beyond the precise letter of her instructions, even if acting within their general framework.

It may indeed be true that the next graduate student down the line would have made the discovery if she hadn't. Yet with this "what-if" argument, almost every scientist could be stripped of his credit, in that every discovery would have been made by somebody else sooner or later. The historical fact is that it was Burnell, and not another individual, who discovered the pulsar signals.

A prize committee which decides that each of two individuals has made an essential contribution to a discovery may then attempt the exercise of determining whose is the more important. Or, it may think further discrimination is futile and award its prize to both. In the case of pulsars, the Nobel committee took the first course, the Franklin Institute of Philadelphia the second. The institute, which prides itself on the thoroughness of its prize-giving investigations—the process usually takes 1½ to 2 years—awarded its Albert A. Michelson medal to Hewish and Burnell jointly in 1973. The institute declines to discuss the basis of the award, but a prize committee official said that when an institute prize is shared, "We are probably recognizing the recipients for equal efforts."

Questions of credit are sometimes so hard and so invidious to resolve that it seems fairer to blame the prize rather than the prize-giver for any inequity of distribution. "It's precisely questions of this kind that make one skeptical about the whole business of the Nobel prize," says George B. Field, professor of astronomy at Harvard. Field, whose attitude to scientific Brownie points is as detached as anyone's—he declined to be elected to the National Academy of Sciences—believes that science is really a social activity, not the endeavor of lone acting heroes which the institution of Nobel prizes presupposes. Be this as it may, the history of the discovery of pulsars admits of almost all the logically possible arguments on the award of the Nobel prize—that Hewish alone should have received it, that Hewish and Burnell should have received it together, that neither should have won it, and that Nobel prize money, founded at a time when science needed this kind of encouragement, should be put to less invidious and more truly useful purposes.—NICHOLAS WADE

# Energy: A Strategic Oil Reserve as a Hedge Against Embargoes

Disagreement over energy policy between the White House and Congress, and between majority and minority factions within Congress, has been a hallmark of the 1975 legislative year. Yet, amid all the disagreement over oil pricing policies and other energy issues, there has been one important proposition that has enjoyed strong support in Congress as well as in the Executive Branch.

It is that, whatever else is done, the nation should hedge against the possibility of another Arab embargo by establishing a sizable strategic oil reserve, with artificial caverns in Gulf Coast salt domes to be used as the principal repositories; and, further, that the long-neglected naval petroleum reserves should be fully developed as a source of oil for the strategic reserve and for the civilian economy. Now there looks to be a better than even chance that effective action will be taken on this twofold proposition before the year is out.

In his State of the Union message last January, President Ford asked for emergency legislation for strategic storage of 1 billion barrels of oil for civilian needs and 300 million barrels for defense purposes. Such a reserve, coupled with emergency conservation measures, would be expected to compensate for as long as 1 year for an embargo occurring in 1980 or thereafter. The President also asked for quick legislative action to open up the Elk Hills naval petroleum reserve in California. If fully developed, Elk Hills might itself be able to produce enough oil for the strategic reserve.

Although Congress has not yet delivered on the President's requests, it has begun to act. On 8 July, the Senate passed, by 91 to 0, a bill to establish a system of strategic reserves that would include a 3-month supply of crude oil, together with emergency supplies of petroleum products for industry and for any region (such as New England) particularly dependent on imported oil. While this system would not measure up to what President Ford has proposed, the White House would no doubt regard it as representing a significant step in the right direction.

On the same day that the Senate acted, the House of Representatives voted overwhelmingly to allow the naval petroleum reserves to be transferred from the Navy Department to the Department of the Interior. These include Petroleum Reserve No. 4 in Alaska, on the North Slope, as well as Elk Hills (the Teapot Dome reserve in Wyoming and the Buena Vista Hills reserve in California would be part of the transfer, but these are not significant resources).

"Pet 4," as the Alaskan reserve is called, is almost completely undeveloped. Its proved reserves total no more than 100 million barrels. But, with its estimated reserves ranging from 10 billion to 33 billion barrels, Pet 4's ultimate potential may equal and perhaps far surpass that of the adjoining Prudhoe Bay field, which is expected to be producing up to 2 million barrels a day in the 1980's. Although President Ford asked for authority to explore *and develop* this reserve, the House bill would merely authorize an expanded program of exploration.

Although a thousand productive wells have been drilled at Elk Hills since the reserve was created in 1909, the field is now essentially shut-in. The House bill would open up the reserve and have it developed further, with production rising over a 3-year period to a maximum efficient rate of about 300,000 barrels a day. As reported from committee, the bill would have limited the Elk Hills contribution to the strategic reserve to about one-fourth of the production there. But this limitation was eliminated on the House floor. Otherwise,