Nobody thought we needed xerography until we had it

COPIES IN SECONDS

BY DAVID OWEN

A FRIEND OF MINE CALLED NOT LONG AGO TO ASK IF I would send him a copy of a certain newspaper clipping. I said I would. I rooted around in the stuff on my desk and found the clipping near the bottom of a big stack of papers. I moved it to the top and made a mental note to take it to the drugstore across the street, which has a coin-operated photocopier. Because I don't work in an office, I can't just run down the hall and make a few thousand free copies of a clipping, a recipe, my hand, a newsy Christmas poem describing my family's heartwarming experiences during the previous year, or anything else.

Several days passed. Every time I went out, I either forgot about the clipping or remembered it and decided not to do anything about it. If there's anything I hate, it's carrying around a large, loose, irregularly shaped piece of paper while I do various errands. If someone had grabbed me by the cheeks and told me to march right over there and make that copy, I would have replied, like Bartleby, "I would prefer not to." I toyed with the idea of retyping the entire newspaper article—a pleasant way to spend an afternoon. Gradually the distance between my apartment and the drugstore grew in my mind to the point where it might as well have been the distance between St. Louis and the moon.

Then, early one morning as I lay sleepless in bed, I came to the sudden, powerful realization that I would never make that copy unless I made it on one of those little personal copiers that Jack Klugman is so enthusiastic about on television. The necessity for making large expenditures often comes to me in such a flash. I now believed, in other words, that walking across the street to spend twenty cents for a single photocopy was less convenient and more irrational than driving across town to spend several hundred dollars on an entire machine that I would then have to find a permanent place for in my apartment.

The next day I drove over to a discount electronics store and bought a Canon PC-10 personal copier for $475. (This was quite a bargain; the manufacturer's suggested retail price is $795.) Canon personal copiers use special cartridges that contain, as Jack Klugman says, "the entire copying process." The cartridges are sold separately. I bought two, for about fifty dollars each. I also bought five 500-sheet packages of ordinary paper, which were on sale, for a total of just $15.

A Canon personal copier is very small—about the size of two toaster ovens. But the box it comes in is very large—about the size of six or seven toaster ovens. Maneuvering the box and the cartridges and all that paper up to my apartment turned out to be quite a problem. I finally made it, though, and set up the machine without much trouble. I put the clipping on the platen, inserted a sheet of paper, and watched a crisp, clean copy emerge from the other end.

A feeling of well-being and deep inner satisfaction coursed through my veins and arteries. My life had achieved a sleek new efficiency. I could now enjoy in my own home a pleasure usually known only to people who have real jobs. "So long, sucker," I imagined myself saying to the man who runs the drugstore across the street.

I made another copy of the same clipping and threw away the first one. Then I made a third and threw away the second. Then, after a panicky moment in which I wondered whether I had not just satisfied my copying needs in their entirety, I opened the owner's manual and began, page by page, to copy that.

EVEN IN THE DAYS WHEN I HATED MAKING COPIES, the ability to do so was something I took for granted. Much of journalism consists of photocopying things that other people have written and finding slightly different ways to write them again. Obviously, this has not always been possible. Twenty-seven years ago Jodi Stutz could not have lost her job at Deere & Company, in Moline, Illinois, as she did in 1980, for making a Xerox copy of her bare bottom, because twenty-seven years ago Xerox office copiers did not exist. Until relatively recently, making facsimiles of ordinary business documents was so difficult and expensive that almost no one bothered to do it.

The first office copiers were, as is well known, monks. When Gutenberg invented movable type, in the early 1400s, monkdom trembled. Some time afterward the Abbot of Sponheim wrote a lengthy treatise arguing that monks "should not stop copying because of the invention of printing." To ensure that his treatise got the readership it deserved, the Abbot had it printed. A couple of hundred

Chester Carlson at forty-four and at eighteen. Clockwise: a key patent; a medal for the invention; Carlson's pen; the first dry copy; a patent drawing; Carlson's glasses

years went by. In the mid-1600s someone pressed a moist piece of tissue paper against a written document, causing some of the ink of the original to transfer to the tissue. A couple hundred more years went by. Blueprints were invented in 1842. Typewriters, carbon paper, and mimeograph machines were introduced a few decades later.

Carbon paper and mimeograph machines were improvements over hand copying, but neither could be used to reproduce documents that already existed. Mimeography, furthermore, was a terribly inefficient way to make a small number of copies, since each document required its own master. Schoolchildren love mimeograph copies, because they smell so terrible, but almost everyone else hates them. Photostat machines, which were introduced in the early 1900s and which make copies photographically on sensitized paper, were much too expensive for ordinary office use. They were also too big, too slow, and too hard to use. When a businessman needed a copy of something, he generally called in the functional equivalent of a monk.

This didn't really begin to change until the middle of our century, 500 years after Gutenberg. In the early 1950s the Minnesota Mining and Manufacturing Company (3M) and Eastman Kodak introduced office copiers called, respectively, Thermo-Fax and Verifax. Both were small and inexpensive. Their chief drawback was that they made dreadful copies. Thermo-Fax used a heat-sensitive paper that tended to continue darkening long after it had left the machine. Verifax produced copies that were even stinkier than mimeographs. Neither machine made copies that were archival, or permanent. Both machines required special paper, which over time cost users a fortune.

Office copying as we know it didn't arrive until 1960. That year a small company in Rochester, New York, began marketing its Haloid XeroX 914 Office Copier (the second capitalized *X* is a flourish that the company later dropped). The 914, unlike its competitors, made good, permanent copies on ordinary paper. The machine, though large, was simple enough for a child to use. Haloid Xerox, Inc., (which had started life as the Haloid Company and is known today as the Xerox Corporation) had been marketing a small number of machines employing its revolutionary copying technique for a decade, but the 914, the first model intended for general office use, was also the first to catch on in a big way. The number of copies made in American offices grew from around 20 million in 1955 to 14 billion in 1966 to approximately eleventy zillion today.*

It is often interesting to speculate on what life would be like if some conspicuous element of it were removed. Suppose, for example, that the universe contained no solid material that was also transparent—no glass or plastic or anything similar. Without such a substance we would have no windshields, no light bulbs, no contact lenses, no (good) aquariums, no television sets, and so on. What would we do? The loss of xerography—as the plain-paper copying process that Xerox introduced is known—would be less dramatic, but its impact would still be profound. We would have no Pentagon Papers, fewer lawyers, more secrets, larger forests, more (fewer?) bureaucrats, less espionage, better memories, fewer cartoons on our refrigerators, and a lot less information in general. Xerography places rapid mass communication within the reach of almost anyone. To see how potent and indeed subversive such a capability can be, one need look no further than the Soviet Union, where copiers are more closely guarded than computers.

The Xerox machine has given ordinary people an extraordinary means of preserving and sharing all sorts of information. And yet we take it for granted. The usual cure for this sort of neglect is to focus obsessive attention on the subject for a short time and then never think about it again. This is what I intend to do.

MOST PEOPLE SPEND MORE TIME THINKING ABOUT how photocopiers don't work than about how they do. "Call key operator" and "Check paper path" have become familiar modern imperatives on a level with "Fasten seat belt" and "Shake well before using." It is commonly believed that the stubbornness of many photocopiers results from the same declining attention to quality that makes the present in all respects worse than the past. But this is not the case. A xerographic copier is a marvel of extremely intricate engineering that, like the Post Office, actually works much better than one has any right to expect.

Every photocopier that uses ordinary paper employs some version of the basic xerographic technology embodied in the Haloid XeroX 914. At the heart of this technology is a specially treated surface, usually in the shape of a cylinder, that is known as the photoreceptor. In the 914 the photoreceptor was made of the element selenium. Like a balloon that has been rubbed against a wool sweater on a cold day, selenium is capable of holding an electrical charge. Unlike a balloon, selenium is capable of holding this charge only in the dark. If you shine a light on a charged piece of selenium, the charge will vanish from every part that is illuminated.

If you shine the light on a printed page so that an image of the page is projected onto a charged selenium drum, the drum will retain its charge in those places where no light falls (that is, in those places corresponding to the dark ink on the page) and lose it everywhere else. If you then sprinkle the drum with an oppositely charged powdered ink, the ink will stick to the charged parts of the selenium surface, in the same way that house dust sticks to a staticky balloon. This produces on the surface of the drum an exact

*Some of the statistics in this paragraph are made up. According to the public-relations office at Xerox, the world made 522 billion copies last year on xerographic machines sold by Xerox and its competitors. No one knows the exact number, though, because many copies don't get counted. No one, for example, has called me to ask how many copies I have made of the credit cards in my wallet (three), so estimates are off by at least that number. The Xerox Corporation makes more copies each year simply in testing its machines than the entire world made for all purposes thirty years ago.

mirror image of the original printed page. The drum rolls over a piece of paper, transferring the image to it. The copy is made permanent in a device called a fuser, a small heater that melts the powdered ink and binds it to the page.

A small, unrepresentative minority of readers will undoubtedly write in to claim that they thought of just such a process back in 1930 or so and would I please ask Xerox to send along a royalty check as soon as possible. These readers, though valued as subscribers, must be dismissed as crackpots. Xerography is unusual among inventions in having been conceived by a single person. There was no one in France or Russia who was working on the same thing. The Chinese did not invent it in the eleventh century B.C.

COURTESY XEROX CORPORATION

Chester Carlson with the materials he used to produce the first xerographic copy, in 1938

The inventor of xerography was a shy, quiet man named Chester Carlson. For a full decade electrophotography, as he called the process, was his private obsession. No one took him seriously except his wife. All of the twenty-one major corporations he approached expressed a total lack of interest, thus passing up a chance to manufacture what would later be called, more than once, the most successful commercial product in history. So persistent was this failure of capitalistic vision that by the time the 914 Office Copier went into production, the original patent covering its internal processes had expired.

CHESTER CARLSON WAS BORN IN SEATTLE IN 1906. HIS mother died of tuberculosis when he was seventeen. His father was an itinerant barber crippled by arthritis. The family moved briefly to Mexico for therapeutic reasons, and then for financial reasons settled in a remote and impoverished corner of California's San Bernardino Valley, where Carlson was sometimes the only student in the local school. He worked his way through junior college and the California Institute of Technology, from which he graduated with a degree in physics. After college he worked for a short time as a researcher at Bell Telephone Laboratories. He ended up in the New York patent office of a small electronics outfit called P. R. Mallory & Company.

Carlson said in the early 1960s, in a short film produced by Xerox, "In the course of my patent work I frequently had need for copies of patent specifications and drawings, and there was no really convenient way of getting them at that time." Specifications had to be retyped and then proofread for errors; technical drawings had to be sent out of the office to be copied, at great expense, on a Photostat machine. Carlson often wished that there were a simpler method. When none presented itself, he decided to invent one.

Carlson approached this task with an unrelenting single-mindedness that one would not hesitate to label lunacy had the outcome been different. Perhaps it was lunacy all the same. For many months he spent spare moments at the New York Public Library, poring over fat technical volumes. He concluded early on that his copying device, whatever it turned out to be, would have to depend on a process "that used light to affect matter in some way." This process could not be photography, he reasoned, because photography was too well understood and had attracted too many well-financed researchers. If photography held the answer, he would not be the one to find it.

One day in the course of his reading Carlson came upon a property called photoconductivity. The electrical conductivity of certain materials, he read, can be affected by exposure to light. Only a very few materials behave in this way. One of them is sulfur. Carlson bought some at a chemical-supply store and tried to liquefy it by holding it over a burner on the kitchen stove, his principal piece of laboratory equipment. The sulfur caught fire and filled his apartment with a cloud of noxious fumes.

Chester Carlson became quite well known in his apartment building. The odor of rotten eggs drifted under his door and permeated the hallways. Small explosions rocked the walls. One day a young neighbor dropped by to complain. Carlson managed to charm her, and she later married him. Somewhat reluctantly the struggling inventor surrendered two of the burners on his stove.

Married life being what it is, Carlson soon gave up the other two burners as well. He moved his laboratory into a small apartment in Queens owned by his mother-in-law. He also hired an assistant, an unemployed German physicist named Otto Kornei. Carlson couldn't afford to pay very much, but Kornei had no other prospects. For several years Carlson had been performing his experiments without success. Now, with Kornei's assistance, he began to make some progress. The two men coated a metal plate with sulfur. Then Carlson wrote the date and place—*10-22-38 Astoria*—in black ink on a glass slide. He rubbed the sulfur-coated plate with a cotton cloth to give it an electrical charge, placed the slide against it, and held them beneath a powerful lamp for a few seconds. He then removed the slide and sprinkled black powder on the plate. Much to his astonishment, a blurred image of his inscription appeared. Hands trembling, Carlson pressed a piece of waxed paper against the plate and peeled away the world's first xerographic copy.

Carlson was elated; Kornei was depressed and disappointed. The little piece of waxed paper didn't look like much to him. (It didn't look like much to me, either, when I saw it in its display case at the Smithsonian Institution.) Fond of Carlson but concerned about his future, Kornei soon accepted a job offer from IBM.

Carlson spent the next five years tinkering with his invention and trying to find a company that could appreciate its potential. IBM, RCA, and General Electric, among others, turned him down. Finally, in 1944, at the end of his wits and the bottom of his bank account, he was led by a chance conversation to the Battelle Memorial Institute, a private research foundation in Columbus, Ohio. Battelle offered to spend $3,000 developing his idea in exchange for 75 percent of future royalties. Carlson happily agreed and began to spend his spare time in Columbus. The next year his wife divorced him.

IN 1945 THE HALOID COMPANY EARNED ABOUT $100,000 manufacturing photographic paper and related supplies in Rochester, New York. This was small potatoes and seemed even smaller, because one of Haloid's closest neighbors was the Eastman Kodak Company. Many Haloid employees believed that Kodak could put them in the poorhouse at any moment and that its failure to do so was a sign less of charity than of indifference. Tired of playing sandlot ball in the shadow of a big-league team, Haloid's top management developed a keen interest in finding another line of business.

One day John Dessauer, Haloid's chief of research, noticed a brief account of Chester Carlson's discovery in a technical journal. Electrophotography sounded promising, so he persuaded Joseph C. Wilson, Haloid's president, to accompany him to Columbus for a demonstration. Wilson, an inspired executive who occupies a nearly deific position in Xerox's corporate memory, was impressed. (Wilson died in 1971, at the age of sixty-one, while having lunch with Nelson and Happy Rockefeller in Manhattan.) Early in 1947 Haloid agreed to support Battelle's research in exchange for the right to manufacture products based on it. This commitment taxed Haloid's limited resources, but Wilson and his lieutenants were more excited by copiers than they were by photographic paper.

Haloid introduced its first xerographic copier in 1949. (The word *xerography* was coined by a classics professor at Haloid's request; it is based on Greek words meaning "dry writing.") This first copier was called the Model A or, more familiarly, the Ox Box. It was a sprawling, awkward device that actually consisted of three separate machines. The selenium photoreceptor was not a drum, as in the 914. It was a flat, heavy plate. The operator had to hoist it from one machine to the next and repeat the entire time-consuming process for every copy. The operating manual was filled with dire instructions:

> Dry the plate surface by striking it lightly and briskly with a clean, dry, UNTOUCHED portion of cotton. . . . With a spoon, carefully spread one-fourth of a teaspoon of XeroX Toner over the developer. . . . When mounted in the process tray, the four tabs of the electrode should protrude no more than approximately 1/64" above the level of the side gaskets, nor should they go below the side gasket.

Haloid shipped out several Model As for field testing. All were quickly returned. "Too complicated" was the verdict. The machine might have disappeared altogether, and taken Haloid with it, had it not serendipitously turned out to be an excellent and inexpensive maker of paper masters for offset printing presses.

(Offset printing is almost impossible to understand. It is based on the principle that oil and water don't mix. You can make a simple offset press by taking a smooth stone and drawing a picture on it with oil; dipping the stone in water, which will adhere to the bare stone but not to the oily image; dipping the stone in a non-water-soluble ink, which will adhere to the oily image but not to the wet stone; and pressing the stone against a piece of paper. In an offset press using a xerographic master the stone is replaced by a piece of paper and the oil is replaced by a powdered ink that repels water. Before xerography came along, offset masters had to be made using a complicated photographic process.)

A handful of other clunky xerographic products followed the Ox Box over the next decade. All found narrow applications and small but adequate numbers of devoted users, but none was the compact, automatic office copier that Carlson and Haloid dreamed of. Work on this machine proceeded alongside the other projects, but progress was slow.

"Xerography went through many stages in its development at which any sane management committee would have been justified in turning it down," a Battelle staffer said later. "There always had to be something extralogical about continuing."

Carlson continued to contribute to the development of

his invention, first as a frequent visitor at Battelle and later as a consultant at Haloid. Rapidly, though, the responsibility for realizing his vision was transferred to others. When the 914 took off, his royalties made him an extremely wealthy man. Carlson retired to a large house on Clover Street, in Rochester, where he and his second wife entertained friends by burning incense and conducting séances. He died in 1968.

When John Rutkus came to the Haloid company, in 1955, his first assignment was to make himself a desk. Money was scarce in those days. All available resources were being pumped into the development of xerography. Rutkus was an engineer. He took an old drafting table and positioned the top to lie flat.

Rutkus's second assignment was to create a rough design for the machine that would become the 914. The original goal at Haloid was to build an office copier that would be small enough to sit on a desk. It soon became clear that this goal was unrealistic. The copier that began to take shape on Rutkus's drawing board was more nearly the size of a desk.

Blocking out the internal design of the 914 required a great deal of imagination, because almost none of the systems that would constitute it had been perfected, or even conceived. The research and engineering departments worked side by side, inventing the machine as they went along. For example, Haloid was determined to build a copier that used cut sheets of paper. This produced enormous problems. Xerography involves the creation of an effect similar to static electricity, and when a piece of paper comes in contact with a charged photoreceptor, it sticks like wallpaper. How to peel it off? Vacuum systems didn't work, because they tended to slurp up the powdered ink. Mechanical grippers marred the delicate surface of the drum. One day, while pumping up a child's bicycle tire in his garage, Rutkus conceived of a system in which tiny nozzles would lift the leading edge of each sheet with puffs of air. He stuck a piece of paper to the hood of his car and blew it off with the bicycle pump. The idea was incorporated in the machine.

Haloid didn't have enough money to build custom parts for its pre-production models. Bolts, springs, and pieces of old cars were scavenged from a junkyard on Clinton Avenue, in Rochester. The plan for the 914 called for a photoreceptor drum about eight inches in diameter. The engineers tried welding sheets of metal into cylinders and coating them with selenium, but they couldn't get the selenium to stick to the welds. At the junkyard one day an engineer stumbled over a length of discarded aluminum pipe. He took out his tape measure. The outside diameter was eight and a half inches. He bought ten feet, took it to a couple of brothers who ran a small machine shop nearby, and had them tool it down. The pipe was cut into short lengths, coated with selenium, and installed in the machines.

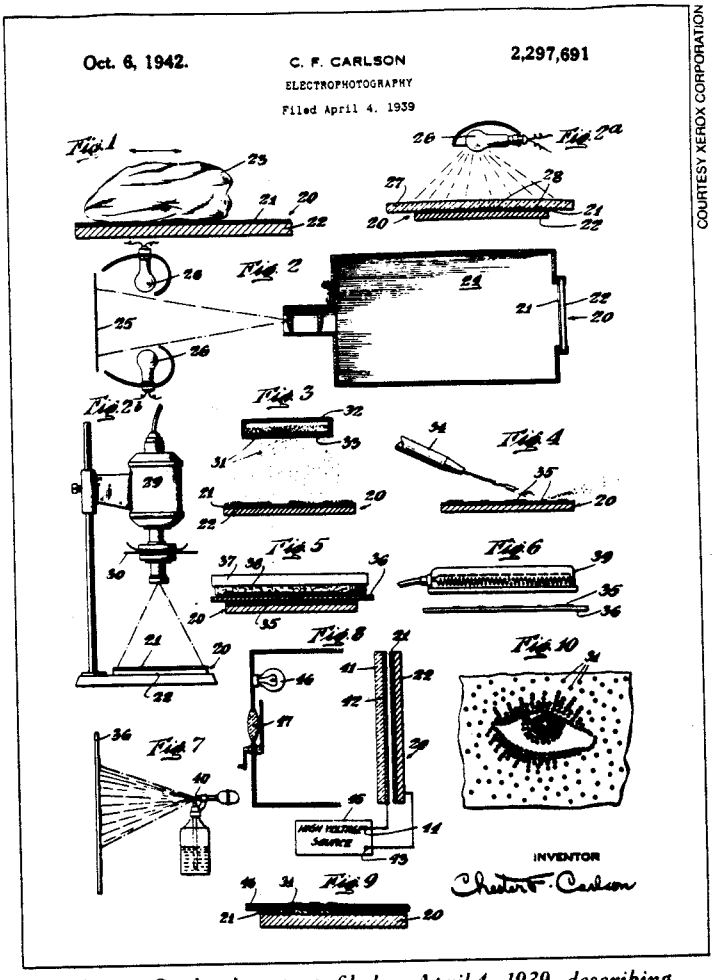
Another problem was the powdered ink, or toner: no one knew how to make one that would work. Haloid's toner plant was nothing more than a drafty old garage on Avis Street. (The optical group was located in the basement of a Masonic temple.) People who worked there went home each night looking like coal miners. The 914 required a toner that would fuse with paper at a low temperature, because heat destroys the photoconductivity of selenium. Avis Street periodically came up with promising batches, but then the engineers would change the design of the fuser and hand down a new set of specifications. Sizing was also a problem. New batches of toner frequently contained large, anthracitic chunks, referred to by the engineers as charcoal. When a piece of charcoal got into a machine, it ended up as a smoking blob in the middle of a piece of paper. Often it also wrecked the photoreceptor. The head of the toner group complained that the engineers were making impossible demands, but finding an acceptable formula was a do-or-die proposition. "If we hadn't accomplished the lower-melt toner," Rutkus said later, "we wouldn't have had a product." In the meantime Haloid simply proceeded on the assumption that a suitable toner would be found.

Producing toner was one problem; getting rid of it was another. Nearly a third of the toner that forms each image remains stuck to the photoreceptor after a copy is made. This residue has to be cleaned away. With the Ox Box cleaning had had to be done manually, by rocking the selenium plate back and forth in a tray filled with diatomaceous earth—a pale, claylike powder composed of the remains of tiny organisms. (Earlier models had used coffee grounds, soybean meal, flax seed, and corn meal; all attracted mice.)

The 914 was going to be fully automatic, so a different method had to be used. The designers settled on a rotating fur brush. Beaver and raccoon pelts were tried and rejected. The belly fur of Australian rabbits, it was discovered, worked just about right. The brush had to be trimmed to a very tight tolerance: if the fur was too short, it wouldn't clean the drum; if it was too long, it would mar the surface. The engineer who supervised the final production of the 914, Horace Becker, took a rabbit pelt to a local furrier named Crosby Frisian and asked him if he could trim it to the proper length, give or take a sixty-fourth of an inch. Frisian's business was making fur coats. He took the yellow tape measure from around his neck and said, "Show me what a sixty-fourth is."

Even after the toner problems had been solved, the 914 was liable to burst into flames. If paper didn't move through the fuser fast enough, it caught fire. Haloid's early copiers had contained fire extinguishers that kept the heat away from the drum and held damage to a minimum. The engineers began to design a similar system for the 914. Work proceeded apace until the marketing department found out. Fire extinguishers in an office machine? They were incredulous. *Fire*, which had always been a problem with xerographic machines, was a word that did not cross

their lips. When they discussed the problem at all, they called it *scorching*. Black smoke and orange flame could be billowing from a machine and the Haloid repairman would scratch his head and say, "Hmmm, there seems to be a little scorching here." At last a compromise was reached. Fire extinguishers were included, but they were called scorch eliminators.



COURTESY XEROX CORPORATION

Chester Carlson's patent, filed on April 4, 1939, describing his invention: electrophotography

NEAR THE END OF its harrowing effort to develop the 914, Haloid suffered a momentary failure of nerve. The company had no manufacturing facilities to speak of. Demand for its early copiers had never been large enough to require anything so grand as a factory. As the day of reckoning drew near, Joseph Wilson decided that he owed it to his stockholders to explore less risky methods of bringing the 914 to market. He invited IBM to consider a joint venture. IBM hired Arthur D. Little, an old and distinguished management-consulting firm in Boston, to determine just how large the market for an office copier might be.

Haloid had already conducted an impromptu study of the same question. A couple of young salesmen had traveled to several northeastern cities and asked people in various businesses how many copies they used. Thermo-Fax and Verifax were already on the market, so people had begun to develop a sense of what office copiers could do. In Philadelphia one day, one of the salesmen stopped by the local Social Security office, which used one of the new coated-paper machines.

"How much of that paper do you use?" he asked.

"What do you mean—how many carloads, or what?"

The Haloid man's eyes lit up. *"Carloads?"*

The consultants from Arthur D. Little came to a very different conclusion. The copier was far too large and expensive to find a market, they said. The nation's total demand, now and in the future, could be satisfied by a maximum of 5,000 machines. "Model 914," their report concluded, "has no future in the office copying market." IBM politely declined to become involved.

Haloid's executives swallowed hard but elected to go ahead. The first production model rolled off the assembly line in 1959. "Rolled off" is literally correct: the first 914s were assembled on wooden pallets with wheels on them. When a worker finished with his part of the machine, he pushed the pallet to the next station. The pallet could be tilted sideways so that the copier, which was the size of a deep freezer and weighed more than 600 pounds, could be squeezed through an office door.

Demonstrating the 914 was difficult. Only a few of the machines existed (at first the factory turned out just five a day), and they were too big to tote around. The solution, Haloid decided, was television. The company had spent so much money that spending even more was eerily euphoric. The 914 commercial, which first aired in 1960, showed a businessman at a desk.

"Debbie, will you please go make a copy of this?" the man asks a little girl.

"Okay, Daddy," she says.

"That's my secretary."

Debbie goes skipping off and copies the letter by pressing a single button. A voice explains that the 914 makes a first copy in less than a minute and produces seven copies a minute after that. Debbie scoops up the copy, turns, stops, and goes back to make a copy of her doll.

"Thank you, Debbie," her dad says. "That was fast. Which is the original?"

Debbie looks at the papers and scratches her head. "I forget!"

The Debbie spot and several other major promotional efforts were phenomenally successful. An angry competitor demanded proof that Debbie was not a midget: how could a child operate a machine like that? Haloid, which by now was well on its way to becoming the Xerox Corporation, very nearly found itself with more business than it could handle. The company's revenues grew from $32 million in 1959 to $60 million in 1961 to more than $500 million in 1966. A ten-thousand-dollar investment in Haloid stock in 1960 was worth a million dollars by 1972.

"THE MORE YOU UNDERSTAND ABOUT XEROGRAPHY," Robert Gundlach says, "the more you are amazed that it works." Gundlach must be more amazed than anybody, because no one understands the subject better than he. At last count he held 131 patents, most of them involving xerography. (He has also invented a snowmaking system, a sundial, an unusually comfortable backpack, and a 20,000-volt electrostatic generator that can be manufactured for just five dollars.) Gundlach wasn't officially involved in the development of the 914; by the time that project got under way, he was hard at work on the machines that would follow it. But when members of the 914 team had a problem, they went to him. More often than not he had a solution.

Like many gifted inventors, Gundlach seems to have been spawned by alien beings. When I met him, at the 914's induction into the Smithsonian Institution last year, he was wearing light-blue pants, a light-blue plaid jacket, a light-blue striped shirt, and a light-blue tie with some sort of large bird painted on it. He is tall, gaunt, and tanned—like a rancher. In his office at the Xerox research facility, outside Rochester, he has a small, smooth stone that he likes to spin on the surface of his desk. When he starts it going counterclockwise, it spins along smoothly for a while and then begins to wobble. All of a sudden it reverses direction and spins the other way.

When I first saw this, I wondered whether Gundlach had not just inadvertently revealed an interesting fact about his planet of origin. But it turns out that the spinning stone has a terrestrial explanation. The stone is asymmetrical. When it spins counterclockwise, it starts to vibrate, converting rotational energy to translational. This somehow causes it to reverse direction, making it appear to violate the law of conservation of momentum.

Gundlach's father was also an inventor. His one patent was for Wildroot Cream Oil. When he made his first batch, he put it in a tube, anticipating Brylcreem by many years. Executives at Wildroot, where he worked, didn't like it; they thought it looked like toothpaste. He spent a few years in bitter disappointment. Then the Second World War depleted the nation's supply of alcohol, the principal ingredient of Wildroot's bottled hair tonic. Gundlach's invention was alcohol-free. He added a little more water to it, so that it, too, could be poured from a bottle, and resubmitted it. This time the executives loved it. Reminiscing in his office, Robert Gundlach began to sing: "You'd better get Wildroot Cream Oil, Charlie, start using it today, something, something Cream Oil, Charlie, chasing all the girls away." As a teenager, he spent a summer standing over a large vat in Buffalo, mixing all the Wildroot Cream Oil in the world.

One of Gundlach's most important contributions to the 914 was helping to solve its paper-handling problems. "I had a friend who took physics with me," he said. "Every time we went into an exam he said, 'Force equals mass times acceleration and you can't push on a rope. That's all you need to know about physics.' " You also can't push a piece of paper through a Xerox machine; you have to pull it. In addition to the problems involved in unsticking paper from the photoreceptor drum, there were equally tenacious problems involved in sticking it on in the first place. The 914 had to handle all kinds of paper, from card stock to onionskin, and it had to handle them in all climates and humidities. Paper in New Orleans is soggier than paper in Cincinnati, and it behaves differently in the machine. Different kinds of paper have different kinds of grain, which affects how and whether they will curl. Curl added in one part of the process has to be subtracted in another. The way paper is cut during manufacturing puts a burr on the edges, which makes it difficult to separate one sheet from another. And so on.

Gundlach went into semi-retirement this year. He had reached retirement age, and he needed to pick a date. He selected January 15—exactly thirty-three and a third years, one third of a century, since he had joined the company. He was too valuable to be let go entirely, so Xerox offered him a small staff and his own laboratory, where he still works three days a week. Many of his current efforts are directed at enabling Xerox to enter the very-small-copier market, which is dominated by the Japanese, should it ever decide that it wants to.

THE JAPANESE ARE A CONSTANT SOURCE OF CONCERN at Xerox. Not far from Gundlach's office is a sort of museum of competing copiers, most of them built by Japanese companies. The man in charge of this collection is Hal Bogdonoff. Like the commander of the United States Army unit that stands in for the Russians in war games, Bogdonoff has so thoroughly immersed himself in the minds of his adversaries that he now thinks more like them than like his employer. Ask him about a new Xerox product, and he confesses ignorance. Ask him about someone else's machine, and he can describe it from the screws up. His group conducts detailed autopsies of other companies' products, carefully analyzing each new feature and making precise estimates of manufacturing costs.

Among the first things one learns upon tearing apart other people's machines is that there is really no way to make a copy on plain paper other than the way that Chester Carlson invented. There have been a great many advances in xerography over the years, but every machine on the market today takes as its starting point Carlson's original patents. Those patents gave Xerox an extraordinary competitive advantage in the 1960s. Carlson had worked in a patent office, and he knew how to protect an invention. Xerox's monopoly lasted until the 1970s, when the last of the early patents expired.

Xerox's grip on the copying market was tested in three major lawsuits in the 1970s. First Xerox sued IBM for patent infringement. Then, in 1972, the Federal Trade Commission sued Xerox for violating antitrust laws. The next year SCM Corporation sued Xerox for the same thing. All three suits dragged on for years, in part because the inven-

tion of xerography had made it possible for lawyers to turn pre-trial discovery into an open-ended orgy of photocopying. Xerox eventually prevailed in the IBM and SCM suits, but a 1975 settlement with the FTC required it to give its competitors licenses on its office-copier patents.

Xerox did not handle its first taste of real competition with much aplomb. The company's salesmen had been accustomed to sitting around all day with their feet on their desks, waiting for the phone to ring. Now their customers discovered that they had alternatives. In addition, Xerox's breakneck growth in the 1960s had largely destroyed the fraternal spirit that had enabled a rinky-dink company to transform itself into one of the most powerful corporations in the world. In the early days there had been no separation between the research and engineering departments; a discovery by one was savored by both. In the 1970s product development was snarled in bitter bureaucratic rivalries. Meanwhile, the Japanese prospered.

It is greatly to Xerox's credit that it responded to these difficulties not with demands for tariffs and trade restrictions but with a full-scale rethinking of the way it did business. The company began to pay more attention to its customers. It also threw out its old manufacturing system and built a new one on the Japanese model, cutting costs in half. Today Rochester is one of the few cities in the United States that has a positive balance of trade. Copiers assembled at the Xerox plant in Webster, just beyond the city limits, are shipped directly to Japan, where they have done well in a tight market. Here at home, in spite of increasingly stiff competition from the Japanese, Xerox's share of the copier market is actually growing.

Partly because Xerox has been so successful, employees speak of their company's competitors with open admiration. Canon in particular has emerged as a powerful and innovative force in xerography, not only with its tiny personal copiers but also with its larger machines. When I paid my visit to Bogdonoff, he and his staff were especially impressed by an "intelligent" Canon copier that they were dissecting. In place of some of the usual lenses and mirrors the Canon contained a "charged couple device array"—a computer chip that converts light into digital information. This information can be stored in memory or transmitted to a laser printer. The machine can take an image, blow it up vertically, shrink it horizontally, reverse it, take another image from memory, superimpose it on the first, and print the combined picture in a matter of seconds.

I was extremely disappointed to learn that a laser printer is not a dangerous machine in which a ray gun burns crisp black letters on clean sheets of paper. It is, instead, a xerographic device in which the laser is used to "write" directly on the surface of the photoreceptor, which then turns out a hard copy in the manner prescribed by Chester Carlson. As has happened with a number of innovations over the years, Xerox was the first to think of laser printing but not the first to use it in a commercial product.

Laser xerography will play a large role in the much discussed office of the future. A laser, in combination with a microprocessor, makes it possible to create copies without originals. Secretaries, hovering above the floor in streamlined rocket chairs, will create lavishly illustrated documents on their desktop microcomputers and transmit them instantaneously halfway around the world, where they will be printed, collated, and bound on laser copiers without the intervention of human hands.

Actually, everything except the hovering is already being done. In the future it will continue to be done, only more so. Canon builds laser printers and licenses its technology to a number of other companies, including Hewlett-Packard and Apple. Xerox has made up for its early hesitation with several laser printers of its own. As has already begun to be apparent, working in the office of the future will be a lot more fun for secretaries than for executives, who will spend more and more of their time figuring out ways to lay their hands on some of that neat stuff.

LOOKING BACK FROM MY RELATIVELY MODEST HOME office of the present, I find it amusing to consider how unfamiliar xerography once seemed. Shortly after the 914 was introduced, a journal for librarians pointed out, in the tone of voice that Christopher Columbus must have used to describe the New World to Queen Isabella, that the curious new machine might be used to make copies of old books. In a 1967 *New Yorker* article about the Xerox Corporation, John Brooks described an even more astonishing application:

> One rather odd use of xerography insures that brides get the wedding presents they want. The prospective bride submits her list of preferred presents to a department store; the store sends the list to its bridal-registry counter, which is equipped with a Xerox copier; each friend of the bride, having been tactfully briefed in advance, comes to this counter and is issued a copy of the list, whereupon he does his shopping and then returns the copy with the purchased items checked off, so that the master list may be revised and thus ready for the next donor. ("Hymen, iö Hymen, Hymen!")

I suppose that in the early days of the automobile it was not thought unusual to point out that the new invention might be employed to "facilitate travel," and so on. Nowadays I find it much more difficult to discover things that xerography *cannot* be used for. I now have at least two of almost everything I once had one of. My only regret is that these copies were made without the intervention of a laser. I mentioned this to a friend, who in turn showed me an article from *The New York Times* in which it was pointed out that much of the photocopying done today is entirely unnecessary.

An interesting point, I thought. I took the clipping home and made a copy. □

A patent drawing; an aluminum drum; early nameplates; Model A copiers; the first 914; C. Peter McCollough and Joseph C. Wilson, of Haloid; a sales brochure; selenium pellets