'Satiable Curtiosity

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An adaption of "The Elephant's Child"

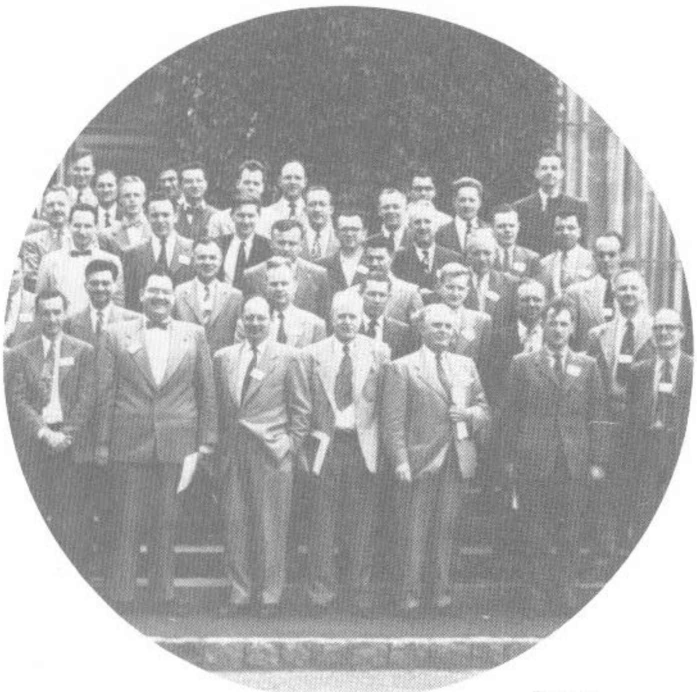


Figure 1
Bell Laboratory, June 1952.

In the High and Far-Off Times the Elephant, O Best Beloved, had no trunk. He had only a blackish, bulgy nose, as big as a boot, that he could wriggle about from side to side; but he couldn't pick up things with it. But there was one Elephant—a new Elephant—an Elephant's Child—who was full of 'satiable curtiosity, and that means he asked ever so many questions.

One fine morning in the middle of the Precession of the Equinoxes this 'satiable Elephant's Child asked a new fine question that he had never asked before. He asked, 'What does the Crocodile have for dinner?' Then his family all said, 'Hush!' in a loud and dretful tone, and spanked him immediately and directly, without stopping, for a long time.

By and by, when that was finished, he came upon Kolokolo Bird sitting in the middle of a wait-a-bit thorn-bush, and he said, 'My father has spanked me, and my mother has spanked me; all my aunts and uncles have spanked me for my 'satiable curtiosity; and still *I want to know what the Crocodile has for dinner!'*

Then Kolokolo Bird said, with a mournful cry, 'Go to the banks of the great grey-green, greasy Limpopo River, all set about with fever-trees, and find out.'

That very next morning this 'satiable Elephant's Child said to all his dear families, 'Good-bye. I am going to the great grey-green, greasy Limpopo River, all set about with fever-trees, to find out what the Crocodile has for dinner.'

He went from Graham's Town to Kimberley, and from Kimberley to Khama's Country, and from Khama's Country he went east by north, till at last he came to the banks of the great grey-green, greasy Limpopo River, all set about with fever-trees, precisely as Kolokolo Bird had said.

Now you must know and understand, O Best Beloved, that till that very week, and day, and hour, and minute, this 'satiable Elephant's Child had never seen a Crocodile, and did not know what one was like. It was all his 'satiable curtiosity.

The first thing that he found was a Bi-Coloured-Python-Rock-Snake curled round a rock.

''Scuse me,' said the Elephant's Child most politely, 'but have you seen such a thing as a Crocodile in these promiscuous parts?'

'Have I seen a Crocodile?' said the Bi-Coloured-Python-Rock-Snake, in a voice of dretful scorn. 'What will you ask me next?'

''Scuse me,' said the Elephant's Child, 'but could you kindly tell me what he has for dinner?'

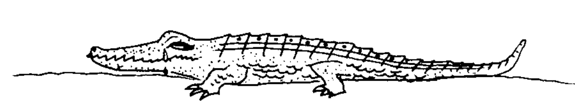
Then the Bi-Coloured-Python-Rock-Snake uncoiled himself very quickly from the rock, and spanked the Elephant's Child with his scalesome, flailsome tail.

So he said good-bye very politely to the Bi-Coloured-Python-Rock-Snake, and helped to coil him up on the rock again, and went on a little warm, but not at all astonished, till he trod on what he thought was a log of wood at the very edge of the great grey-green, greasy Limpopo River, all set about with fever-trees.

But it was really the Crocodile, O Best Beloved, and the Crocodile winked one eye—like this!

''Scuse me,' said the Elephant's Child most politely, 'but do you happen to have seen a Crocodile in these promiscuous parts?'

'Come hither, Little One,' said the Crocodile, 'for I am the Crocodile,' and he wept crocodile-tears to show it was quite true.



Then the Elephant's Child grew all breathless, and panted, and kneeled down on the bank and said, 'You are the very person I have been looking for all these long days. Will you please tell me what you have for dinner?'

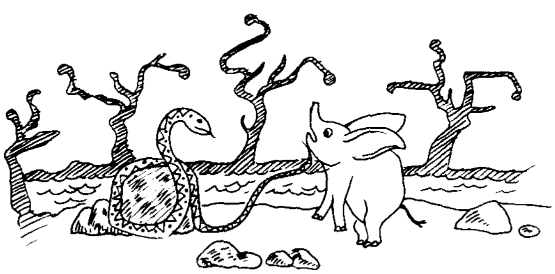
'Come hither, Little One,' said the Crocodile, 'and I'll whisper.'

and Scientific Progress

I'd like to talk this evening about 'satiable curtiosity and scientific progress. It is not a deep scientific topic. I want to begin by sharing with you one of my favorite stories and then I'd like to consider the relevance of the message in this story from my personal experience at Bell Laboratories. The story is "The Elephant's Child," or "How the Elephant Got His Trunk," a story by Rudyard Kipling which many of you probably already know. This is the way it goes, in a somewhat abbreviated form:

* A transcript of the Von Hippel address presented November 28, 1984 at the Fall Meeting, Boston.

from Rudyard Kipling's *Just So Stories*, 1902



Then the Elephant's Child put his head down close to the Crocodile's musky, tusky mouth, and the Crocodile caught him by his little nose, which up to that very week, day, hour, and minute, had been no bigger than a boot, though much more useful.

'I think,' said the Crocodile—'I think to-day I will begin with Elephant's Child!''

At this, O Best Beloved, the Elephant's Child was much annoyed, and he said, speaking through his nose, like this, 'Led go! You are Hurtig be!'

Then the Bi-Coloured-Python-Rock-Snake scuffled down from the bank and said, 'My young friend, if you do not now immediately and instantly, pull as hard as ever you can, it is my opinion that your acquaintance in the large-pattern leather ulster' (and by this he meant the Crocodile) 'will jerk you into yonder limpid stream before you can say Jack Robinson.'

This is the way Bi-Coloured-Python-Rock Snakes always talk.

Then the Elephant's Child sat back on his little haunches, and pulled, and pulled, and pulled, and his nose began to stretch. And the Crocodile floundered into the water, making it all creamy with great sweeps of his tail, and he *pulled, and pulled and pulled.*

And the Elephant's Child's nose kept on stretching; and the Elephant's Child spread all his little four legs and pulled, and pulled and pulled, and his nose kept on stretching; and the Crocodile threshed his tail like an oar, and he *pulled, and pulled, and pulled, and at each pull the Elephant's Child's nose grew longer and longer—and it hurt him hijjus!*

Then the Elephant's Child felt his legs slipping, and he said through his nose, which was now nearly five feet long, 'This is too butch for be!'

Then the Bi-Coloured-Python-Rock-Snake came down from the bank, and knotted himself in a double-clove-hitch round the Elephant's Child's hind legs, and said, 'Rash and inexperienced traveller, we will now seriously devote ourselves to a little high tension, because if we do not, it is my impression that yonder self-propelling man-of-war with the armour-plated upper deck' (and by this, O Best Beloved, he meant the Crocodile), 'will permanently vitiate your future career.'

That is the way all Bi-Coloured-Python-Rock-Snakes always talk.

So he pulled, and the Elephant's Child pulled, and the Crocodile pulled; but the Elephant's Child and the Bi-Coloured-Python-Rock-Snake pulled hardest; and at last the Crocodile let go of the Elephant's Child's nose with a plop that you could hear all up and down the Limpopo.

Then the Elephant's Child sat down most hard and sudden; but first he was careful to say 'Thank you' to the Bi-Coloured-Python-Rock-Snake; and next he was kind to his poor pulled nose, and wrapped it all up in cool banana leaves, and hung it in the great grey-green, greasy Limpopo to cool.

'What are you doing that for?' said the Bi-Coloured-Python-Rock-Snake.

''Scuse me,' said the Elephant's Child, 'but my nose is badly out of shape, and I am waiting for it to shrink.'

'Then you will have to wait a long time,' said the Bi-Coloured-Python-Rock-Snake. Some people do not know what is good for them.'

The Elephant's Child sat there for three days waiting for his nose to shrink. But it never grew any shorter, and, besides, it made him squint. For, O Best Beloved, you will see and understand that the Crocodile had pulled it out into a really truly trunk same as all Elephants have to-day.

Figure 2

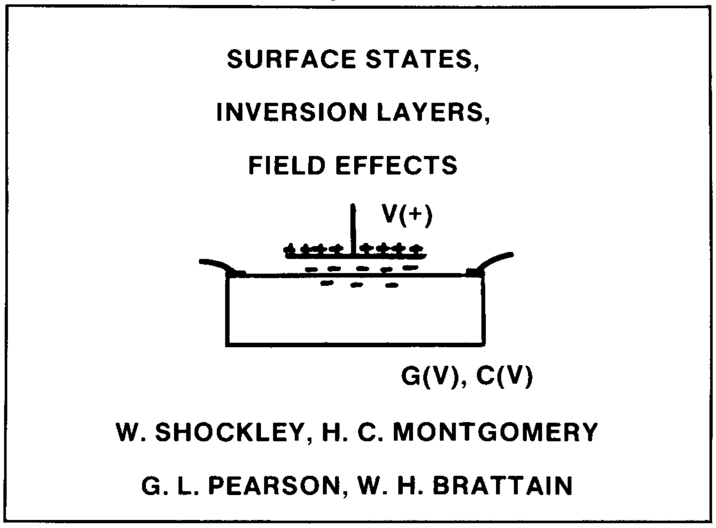
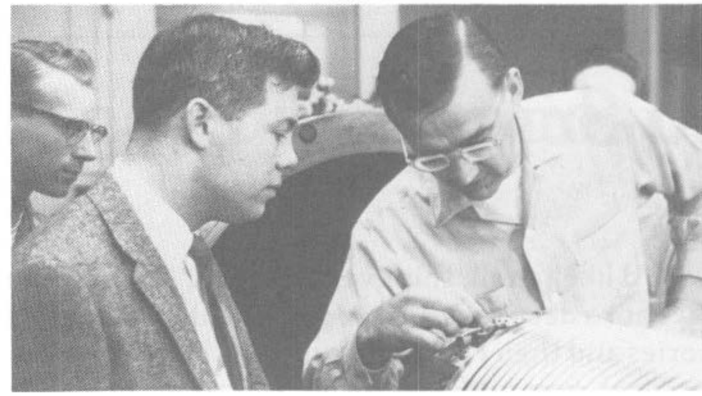
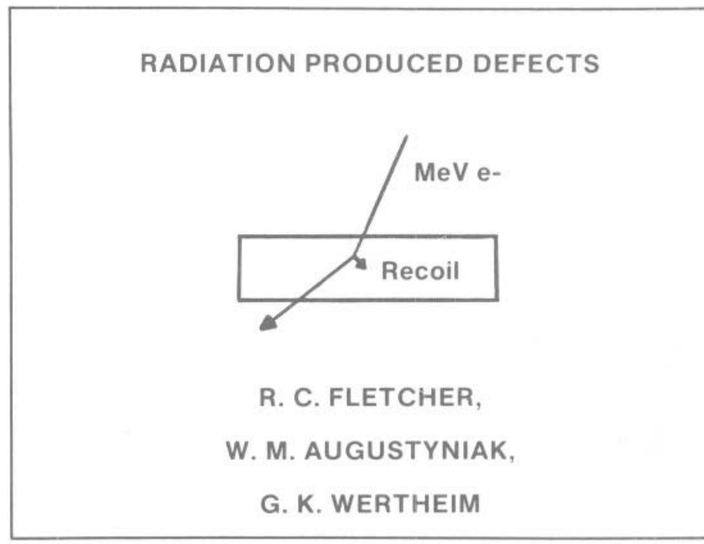


Figure 3





So you see, it was a combination of 'satiable curtiosity and a special challenge that resulted in something very new, and in this case, something very useful, too.

Now I'd like to share with you a few illustrations from my experience at Bell Laboratories, first having to do with semiconductors in the early 1950s when I came to Bell Laboratories. This was an extraordinarily exciting time. The transistor had been invented at Bell Laboratories only a few years before, and the place was an absolute hot bed of people working on all aspects of semiconductor materials and devices. Figure 1 is a part of a picture that was taken in June of 1952 on the steps of the Arnold Auditorium at Murray Hill. It contains part of the extraordinary collection of people who were at Bell Laboratories at that time. It also contains some university professors who had been invited to Bell Laboratories to take part in a series of lectures and laboratory experiments so they could have "hands-on" experience with semiconductor materials and devices and find out what they were all about. The Bell Labs people served as lecturers and laboratory instructors to this group of professors. It was quite an enterprise.

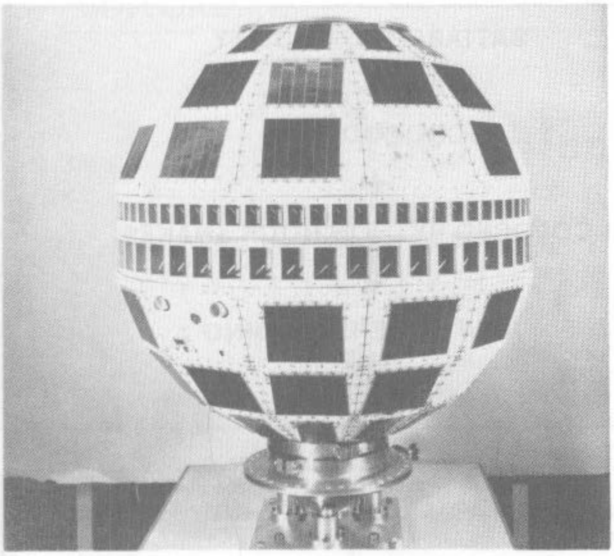
At the bottom right hand corner of the picture is William Shockley, a man of more than modest accomplishments. Next to him is Ian Ross, currently president of Bell Laboratories. Next to him is Shandy Gaucher, a man who did optical and transport measurements on semiconductors, then Walter Brattain, and John Bardeen. Shockley, Bardeen and Brattain were, of course, the inventors of the transistor. Next to Bardeen is big George Dacey, who is currently the president of Sandia National Laboratories, and next to him, at the far left of the front row, is Gerald Pearson, a man who was at Bell Laboratories for many years, but then "retired" to Stanford. Dick Haynes of the Haynes-Shockley carrier drift experiment is standing tall in the upper right-hand corner of the picture. I won't try to identify the rest of the people in the group, and there are a great many important Bell Labs semiconductor materials people who aren't included in the picture: Bill Pfann, Bruce Haney, Joe Burton, Morgan Sparks, Conyers Herring, and others. It was into this group of people that I came as part of Bill Shockley's department, an eager but extremely naive and inexperienced young man.

My first experiments had to do with surface states, inversion layers, and field effects on germanium. They are illustrated in a very simple way in Figure 2. In fact, it was a very simple experiment by modern standards. A metallic electrode was placed physically close to, but not in contact with, the semiconductor surface, and a voltage was applied to the electrode to induce charges on the semiconductor. Measurements were made of the conductance of the semiconducting material and of the capacitance of the condenser of which the semiconductor was one side. These gave interesting revelations about the existence of surfaces states and the way they mopped up charge when it was induced in the semiconductor material and reduced the modulation of the conductance. They showed that inversion layers could be produced by changing the sign of the carriers which were responsible for the conduction. They also showed how this behavior varied with the doping of the semiconductor and the environment which surrounded the surface. It was a really exciting time.

At the bottom of Figure 2 are the names of just four of the people that represented in one way or another bi-colored python rock snakes or crocodiles. Bill Shockley, as a matter of fact, was a bit of both. He was a guy who really stretched people by pulling by both ends, and that turned out to be a very valuable thing for many of us. Harold Montgomery was a man who studied the noise properties of semiconductors at the time. He was a very kindly fellow who clearly was a bi-colored python rock snake who helped me from falling into the great gray-green greasy Limpopo River of inexperience in making electrical measurements. Gerald Pearson was an amazing man. He was an almost infinite resource of information. At the same time, he was a disturbing kind of fellow too, because when I went to Gerald Pearson with something I thought was a hot new idea, Gerald would pull down a notebook off his shelf, thumb through a few pages and say, "Oh, yes, here's the way we did something like that two years ago." Very disturbing.

Walter Brattain is last on this list of four. I don't know how many of you know him, but Walter Brattain is not the most soft-spoken fellow. When I was involved in field effect measurements, Walter Brattain was making measurements of surface photo-voltage effects also trying to learn things about semiconductor services. Walter and I had a friendly competition to see which of us could, or which method was able to, provide more information on the surfaces of semiconductors at that time. Fortunately, it was a much more friendly relationship than existed between the crocodile and the elephant's child in Kipling's story.

Figure 4



I also began to work with radiation-produced defects in semiconductors and chose an approach involving MeV electrons. Because of their light mass, electrons only transfer a very small portion of their energy to germanium atoms in a collision. It was thus possible to make rather simple displaced atom defects in the material. Bob Fletcher and I began to work together in these experiments making use of electrons from a Van deGraaff accelerator in Prof. Trump's laboratory at MIT. (Bob Fletcher is a son of Harvey Fletcher who was the president of Bell Laboratories when Prof. Von Hippel went to visit.) Going back and forth to MIT was rather awkward, and it wasn't very long before I managed to buy a Van de Graaff accelerator so we could continue these measurements ourselves at Murray Hill. That's when I came to recognize the importance of another kind of bi-colored python rock snake, in the person of Walt Augustyniak.

Figure 3 shows me at a somewhat earlier age, and Walt Augustyniak in a characteristic pose. His fingers are in the terminal of the 1-MeV electron Van de Graaff that he maintained and upgraded and utilized with me and with Gunther Wertheim in various experiments over a number of years. Surely it is true that, if it hadn't been for the double clove-hitch he took around my legs with respect to these experiments, I would have slid into the great gray-green greasy Limpopo River while trying to make things work. So there are lots of kinds of bi-colored python rock snakes around.

As a result of my interest in radiation-produced defects in semiconductors and also as a result of the very newly discovered P-N junction particle detectors which were making such an enormous impact in low-energy nuclear physics (I had been a nuclear physicist before I came to Bell Laboratories), when the Bell System decided that it was going to enter the race for space in 1961, I thought it was a terrific opportunity to do something new. The Telstar satellites were destined to go into a very interesting part of space, and there hadn't been very many things going into space anyway up to that time. Of course, the intent of the Bell System's move into space was to establish active communication satellites as a viable medium for long-distance communications. I made a proposition to carry out an experiment. Figure 4 shows a Telstar satellite. Sticking out of it on some of the panels, in addition to the solar cells, are parts of the experiment that we actually did fly on Telstars I and II. In this "race for space," we were trying to make measurements on the radiation belts of high-energy electrons and protons which circled the earth trapped by the earth's magnetic field. Not much was known about these Van Allen Belts and their changes with time. Even less was known about their consequences as far as the useful lifetime of communication satellites was concerned. Here was a chance to fly an experiment, not only to measure the particles directly, but also to measure their effect on electronic materials as well.

Figure 5

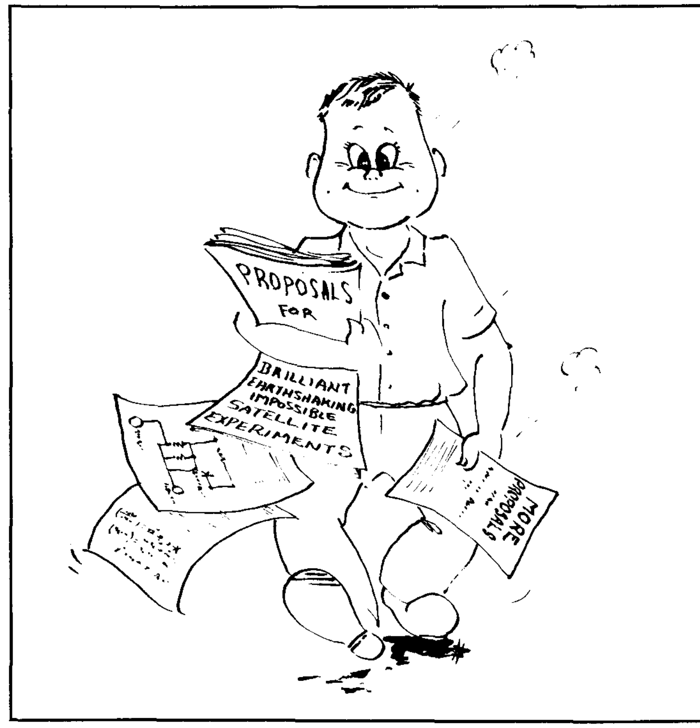


Figure 6

Figure 7

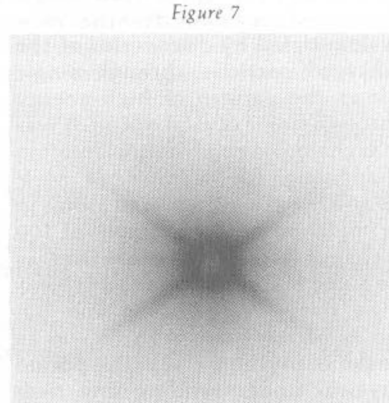
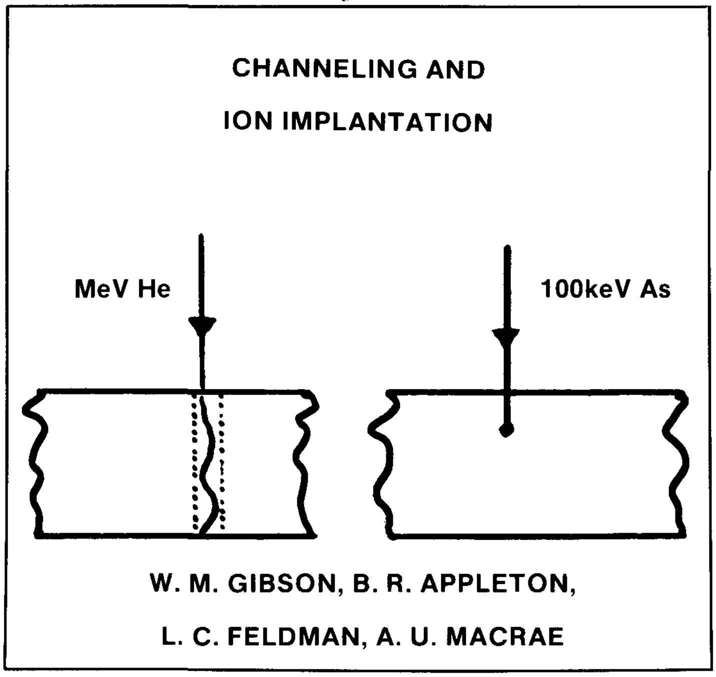


Figure 8



It was a pretty good idea; maybe it was even a very good idea, but it was clear that I was in danger of sliding into the great gray-green greasy Limpopo River for sure in this case. Figure 5 summarizes the situation rather well. This cartoon was drawn by Natalie Miller, Laurie Miller's wife. The person in the cartoon is supposed to be me looking a little cross-eyed. The bundle of papers say, "Proposals for brilliant earth-shaking impossible satellite experiments, more proposals" and so on. It became clear that I was in trouble. Joe Burton was the first of the bi-colored python rock snakes to uncurl himself from around the rock and come down and take a double clove-hitch around my leg to keep me from sliding into the river, pulled by my own ambitious plans for an experiment which I surely could not have carried off.

He helped me to collect and organize a group of people that are listed below who made the whole thing work. Laurie Miller joined us from Brookhaven National Laboratories. He found Izuo Hayashi and Hans Lie who worked on the electronics of the project with him. Tom Buck, Jack Rogers, and George Wheatley developed silicon P-N junction particle detectors which were sufficiently reliable and rugged to stand the rigors of a satellite launch and the environment of space. Les Medford put the satellite packages together. Lou Lanzerotti, Charlie Roberts, and Carol Maclennan were involved in the data reduction and analysis and interpretation. It took a lot of bi-colored python rock snakes to keep me out of this part of the river. It was really an exciting time and it was fantastically busy. Figure 6 shows Carol Maclennan and Charlie Roberts with me and you can see that my hair was turning white.

The next phase of work really started very soon after the "race for space" got underway. It was initiated by discoveries of the channeling of high-energy charged particles through single crystal materials. Figure 7 shows the pattern of high-energy protons that have channeled through single crystal silicon. It was an exciting period of time for me as channeling and ion implantation began to be investigated: Channeling, for example, of MeV helium ions between the planes and the rows of ordered atoms in single crystal materials and the implantation, for example, of 100 keV arsenic ions into silicon to change its electrical properties, as shown in Figure 8. There were some mighty curious and clever young elephants around at the time—Walt Gibson and Bill Appleton and Len Feldman and Al McRae—and my role was as much bi-colored python rock snake as anything else in this period of rapid development of physical understanding and new technology.

Figure 9

'SATIABLE CURTIOSITY

+

CROCODILES

+

BI-COLORED PYTHON ROCK SNAKES

⬇

NEW UNDERSTANDING
AND
NEW TOOLS

Figure 10

'SATIABLE CURTIOSITY

+

A TENSION OF IDEAS

+

A LOT OF HELP

⬇

SCIENTIFIC PROGRESS

The last illustration I'd like to show has to do with laser annealing, a subject which has had a substantial impact at the MRS meetings in Boston since 1978. The idea was pretty nifty. We first heard about it from the Russians who had done some experiments on it. By using a high-powered pulsed laser, or a high-powered cw laser focused to a spot and scanned, you could heat a semiconductor material, either very quickly, or very locally, or both. In that way radiation damage created in the material, for example by ion implantation, could be annealed. No question about it, it worked, although the Russians weren't convinced the process was simply thermal. Very quickly a large number of people became involved in "laser annealing" studies. The following list is clearly incomplete, but it consists of the people who were most vigorously involved, from my point of view, in the very early stages of the game.

From Bell Laboratories—Dave Auston, George Celler, Jene Golovchenko, Ken Jackson, Harry Leamy, John Poate, George Rozgonyi, Dicjk Slusher, Cliff Surko, Venky Venkatesan, and Jim Williams. From Catania—Pietro Baeri, Ugo Compisano, Nuccio Foti, and Emmanuel Rimini. From Oak Ridge National Laboratory—Jagdish Narayan, Woody White, and Rosa Young. From Stanford University—Arno Gat and Jim Gibbons. From Kansas State University—Alvin Compaan. From IBM—Jim Van Vechtan. From IBM and FOM—Franz Saris.

Sometimes in a collection of people like this, it's not easy to tell who are the bi-colored python rock snakes and who are the crocodiles. On the other hand, there is no doubt that the presence of both led to the rapid evolution of the comprehensive understanding we have in this field today.

So, I'd like to return to Kipling. It's clear that for the elephant's child, 'satiable curtiosity, as Kipling phrased it—or insatiable curiosity as we might more commonly phrase it in English today—is the key. 'Satiable curtiosity, plus crocodiles, plus bi-colored python rock snakes, led to new understanding and to new tools (Figure 9). It's certainly clear to me (see Figure 10), and no doubt to each of you as well, that 'satiable curtiosity plus a tension of ideas and a lot of help is what leads to scientific progress.