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# Research by Accident

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ABSTRACT

The article addresses the issue of uncertainty in technological knowledge. "Research by accident" is seen as a central cognitive process to generate (unanticipated) knowledge about the characteristics of a technology. In the example of nuclear weapons, scientific programs have initially led to a sequency of unanticipated discoveries – a process of research by accident that subsequently reveals properties and characteristics of a technology that were not expected initially. The second part of the article deals with cases in which uncertainty originates not in the absence of knowledge per se, but rather with whether knowledge is available in the right form and the right policy context. The example of energy studies of the 1970s illustrates that uncertainty also includes cases where the problem at hand deals with the efficiency of information distribution rather than information generation. There is a difference between (scientific) information that exists somewhere and scientific information that is known in the right context to the right people (the persons with the capacity to take, or to resist, action) at the right time.

## Introduction

We have been warned, if we have a technology in place that causes problems and needs to be replaced with a new alternative, not to be wholly preoccupied with simply accomplishing, with the new technology, what the old technology did.

The new technology, less familiar than the old, may be different in its comparative applications. If you are too much focused on what the problem is you are trying to solve – doing what the old technology accomplished better and without some of its disadvantages – you can miss opportunities inherent in the new technology. You may also fail to recognize some dangers in the new technology – dangers different from the ones that may have made the old technology obsolete.

I shall illustrate the danger with a historical example, an R&D project that appears to have been utterly obsessed with accomplishing on a heroic scale what had earlier been accomplished on a comparatively diminutive scale: the development of nuclear weapons. Nuclear weapons were conceived, designed, developed, and engineered by physicists, chemists, mathematicians, and engineers, with the intent of building bombs larger by orders of magnitude than any bombs that had ever been built. And "bombs" is what they had in mind, what they envisioned. What bombs traditionally did was to explode and to ignite – to produce overpressure and shock, to crush structures, to tear things and people apart, to start fires.

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**Unanticipated Discoveries in the Development of Nuclear Weapons**

The people who designed the atomic weapon were careful in calculating the likely energy yields and in translating the energy yields into ground-level overpressure and thermal radiation according to the altitude of burst. They were not anticipating any weapon effects of military significance except blast and thermal radiation; blast and thermal radiation were what bombs produced. As a result, in my interpretation, there were a number of additional significant weapon effects that were not anticipated, not looked for, not tested for, and discovered only by accident. Literally "accident," in most cases, i.e., an unexpected misadventure [1].[1]

Indeed, one could propound a "law" of weapon development: if you have a serious safety problem on the test range that is hard to eliminate, you have just discovered a new weapon effect!

The first such effect occurred at Hiroshima. It was "prompt" radiation, neutron radiation that caused immediate or nearly immediate radiation sickness (and was later to prove mutagenic). This effect was not observed by the Americans, who had nobody on the ground; it was a discovery of the Japanese. At the altitude of the bombs of Hiroshima and Nagasaki, neutron radiation would not play a major role: anyone within lethal radius of the neutrons would likely be destroyed in the blast damage or by thermal radiation; but a person distant from collapsible structures, protected by white clothing from thermal radiation, could be vulnerable to radiation sickness and death.

This form of radiation was later elevated into a major weapon effect in the concept of the "neutron bomb," or "enhanced radiation weapon," that, though never deployed, received widespread attention and provoked widespread controversy in 1959–1960 and again during the Carter administration. But it was probably unanticipated, because there were no physiologists, or other medical scientists, involved in the atomic bomb development.

The next weapon effect, unanticipated and discovered by "accident," was nuclear fallout. The test of a hydrogen weapon caused a mysterious precipitation to fall on a Japanese fishing vessel, the Lucky Dragon. If the Hiroshima neutrons were "prompt radiation," this was "delayed radiation." Once discovered, as a result of this nuclear-test accident, fallout became recognized as a major weapon effect; some military planners considered it, as a weapon of mass retaliation, more potent than blast and radiation, and not dependent on any significant accuracy. (People my age remember vividly the fallout-shelter campaign of 1960–1961.) Fallout was what the "infernal device" of the movie, *Dr. Strangelove*, was going to destroy the world with.

When American weapon designers wanted to measure the effects of high-altitude bursts they chose Johnston Island, well over the horizon to the southwest of Hawaii. After a test a strange thing occurred: Johnston Island lost radio contact with the mainland for many hours. The earth's magnetic field was disturbed. If this could happen to Johnston Island with a single high-altitude burst in peacetime, imagine what could be done to enemy (or own's own) military communications in war! What began as an unexpected test-range nuisance was recognized as a major nuclear-weapon effect. Furthermore, it required understanding and planning: the burst elevations that one might use against military targets were not those likely to produce the radio effect.

A similar thing happened with another high-altitude shot. This time it was radar blackout, shorter lived than radio blackout, but similarly unexpected, similarly potentially potent militarily. At first it was a test-range annoyance; when recognized it became a

[1] See Cowan and Foray (reference 1) for a taxonomy of research procedures including research by accident.

significant weapon effect. It would have been crucial in attacks confronting antiballistic missile systems.

"Retinal burn" was discovered similarly. Animals were being used to test likely effects on human bodies, especially effects on behavior that might be due to radiation. Some strange behaviors turned out to be due to the fact that many of the rabbits and other creatures had gone blind, some temporarily, some permanently. The flash had burned the retinas of their eyes. But if it could burn rabbit retinas it could burn soldiers' retinas if a nuclear burst—too distant to do them other harm—caught them by surprise looking in the direction of the burst. (An R&D effort was begun to develop safety glasses that would convert from clear to dark quickly enough to protect retinas.)

Still another effect of momentous importance was discovered "by accident" during high-altitude tests at Johnston Island. Electrical equipment that was crucial to monitoring the effects of the blast went out of commission just as the blast went off. This time it clearly couldn't be coincidence. What had just been discovered was "electromagnetic pulse," a sudden pulse of induced electricity that burned out key components. It appeared potentially capable, once understood and designed for (or against), of destroying entire communications systems, a major weapon effect. (Those who saw the TV movie, *The Day After*, some years ago will remember not only the nuclear fallout but the stalled autos in downtown Kansas City.)

A final effect may be worth mentioning because it might have been discovered by accident in an offshore nuclear test. This is the possibility that if a weapon of appropriate yield were detonated at the right ocean depth and the right distance from shore, with due regard to the configuration of the ocean floor, a massive tidal wave—tsunami—might be produced that could inundate coastal cities. This effect was thought of, and indeed taken into account, in the planning of underwater tests. I mention it to highlight the role that even amateur imagination can play in the intellectual exploration for technological effects. This effect—a tidal wave generated by a nuclear weapon—was visualized by a diplomat-scholar-novelist more than half a decade before Leo Szilard delivered Einstein's famous letter to President Roosevelt. In *Public Faces*, published 1933, Harold Nicolson [2] incorporated two technological advances that were to reach fruition only toward the end of World War II, jet (or rocket) engines and atomic bombs. The climax of this extraordinary novel was a British jet-delivered atomic bomb dropped into the Atlantic some 300 miles off the coast of Charleston (as a weapon test!), which generated a tsunami that hit Charleston and two neighboring cities, killing 90,000 people.

I have told this story of unanticipated technological discovery in detail partly because it is almost monotonously faithful to what we were warned against in my first paragraph—being wholly preoccupied with simply accomplishing, with the sought new technology, what the old technology did—and partly because it involves one of the two most expensive and extensive R&D projects ever undertaken (space technology being the other). But I haven't answered the question why so much of the extraordinary potential of nuclear weapons had to be stumbled on. The question deserves an answer that I can't claim to give. But it looks as if several considerations apply.

One is that people were designing bombs to do more and more, and better and better, what bombs had always done; what *else* nuclear bombs might do that was interesting and useful, or interesting and dangerous, was slow to be appreciated. (When proponents of the Strategic Defense Initiative—"Star Wars"—took front stage, "exotic" weapon effects took front stage, too.)

Second may be that secrecy and curiosity are somewhat imcompatible. Only professionals—security-cleared professionals—had access to the technology and to the testing.

Later, schoolchildren would design experiments to be performed aboard the shuttle in outer space; no such access was available during nuclear testing. The Harold Nicolsons who might have known just enough not to know any better than to "invent" radio blackout for fictional excitement couldn't get close enough. (And if they did, they might have been denied the security clearance needed for access to their own writings!)

There is a temptation to attribute this blind stumbling onto newer and newer nuclear potentialities to military predilections, military institutions, a military mindset. But the history of post-war civilian nuclear developments does not clearly appear to be qualitatively superior. The first breathless writing about nuclear energy went overboard with electricity "too cheap to meter." That I think we can excuse as simply bad economics and bad technological thinking: somebody forgot that all you get with nuclear energy is hot water. You still have to generate electricity and transmit it. (Free gasoline doesn't mean free automobiles, free roads, free parking . . . .)

What the early explorers of nuclear energy noticed was that nuclear generation didn't requre any "fuel," anything that had to be "burned." (Nuclear fuel "burns" only metaphorically.) But it was the Navy that recognized the more interesting fact that nuclear energy doesn't require any oxygen! (For anthropological reasons we think of "fuel" as what oxidizes, not as either one of two substances that interact to release energy.) Anaerobic generation of energy was something only submariners — and later, space explorers — could appreciate: air was scarcer than diesel fuel under water.

Least appreciated by early enthusiasts for nuclear energy was what is likely, in decades to come, to be valued more than nuclear energy for electric power — radioisotopes. They have revolutionized medical diagnosis and medical treatment; they have revolutionized physiological research, especially neurological research in the brain; their applications in research seem unlimited. Ironically the evolution of nuclear capability went from the gigantic — the megaton fireball and the 1,000 megawatt power plant — to the molecular.

I have picked on the developers of nuclear energy; let me pick, for a while, on myself and some of my colleagues. During the 1970s and early 1980s I participated in something like five different energy studies. Each of these studies involved 20 or 30 people who shared responsibility for the policy conclusions. Each involved economists, technologists, and political scientists; some involved businessmen from energy-producing or energy-using industries. I recently had occasion to go back and look at all these energy studies to see what we had to say about the environment. The first, sponsored by the Ford Foundation and administered by The Mitre Corporation, was a 2-year study that resulted in a 400-page book [3]; its subject was nuclear energy. The book contained extensive discussions of reactor safety, nuclear wastes, and weapon proliferation, had eight pages on the health effects of burning coal, and two pages on greenhouse gases.

A second study, administered by Resources for the Future and also financed by the Ford Foundation, produced a book [4] that had six references in the index to carbon dioxide and the greenhouse effect adding up to about 10 pages — 10 pages out of 600! We were utterly focused on the "energy crisis" — the oil shortage and the associated inflation. "Greenhouse" hadn't worked its way into the attention of the environmentally concerned scientific community. But I can see no reason why it shouldn't have: enough was known to permit speculation, even analysis of potential consequences. (There was not yet a Harold Nicolson to write the appropriate futuristic novel, or, if there was, this phenomenon hadn't reached his attention.)

In 1979, the Committee for Economic Development published a 62-page booklet that I had written [5]. I had one prefatory paragraph that mentioned environmental health, productivity, and aesthetics, not a word on greenhouse gases. No one ever pointed out my omission of carbon dioxide. No one noticed.

Three years later I participated in a study on energy pricing policy, a joint project of the Committee for Economic Development and the Conservation Foundation. (A co-chairman of the study was William K. Reilly, president of the Conservation Foundation, who headed the Environmental Protection Agency in the Bush Administration.) We reported [6] on the effect of energy pricing on energy technology, energy conservation, new energy resources, inflation, poverty, employment, income distribution, and economic efficiency in general. We included one sentence on the environment in our 75-page report, and nothing on carbon dioxide. In all these cases the study was oriented toward a "well-defined" issue, a tightly defined issue, a consensually recognized issue, an unambiguous issue. In short, an issue that was badly defined for anticipating what would be perceived to be important in the next decade—or even sooner [7].[2]

Carbon dioxide I first heard about from an interesting source: a study group at the National Defense University in Washington, DC, the military services' 1-year course for people at the equivalent rank of colonel. The military, of course, had no responsibility for greenhouse policy; the military wanted only to anticipate what climate change might consist of and what difference it might make for military operations. The Navy wanted to know whether the arctic ice cap would exist in the summertime, and how thick it might be, some decades from now; the army remembered the Battle of the Bulge and the decisive influence of fog. For the military there was no "greenhouse problem," only a potential "greenhouse environment," and they were free to exercise imagination.

My first serious acquantance with the "carbon dioxide problem," as it was then called, was in 1978. The Chancellor of Germany had put the issue on the agenda of a "summit" to be held in Venice, and the White House asked the National Academy of Sciences for advice. (I believe the Chancellor's motivation may have been that his nuclear energy programs were being attacked by greens, and he wanted to publicize the perils of coal.) I, uttely innocent of the subject, was made chairman of a committee of 12 and had to educate myself in a hurry. It is pertinent to report here that among the very few people I found who had a broad background in the subject were Jesse Ausubel and Bill Clark, both International Institute for Applied Systems Analysis (IIASA) alumni, and of course Roger Revelle, well known to IIASA. I never, at the time, discovered any other research organization that had done integrated work on the subject. Individuals worked on aspects of the subject, at numerous locations; only at IIASA did the topic appear to have organized itself. The National Academy had indeed set up a committee a few years earlier, headed by Jules Charney, to examine the likely "global warming" due to an increase in $CO_2$. It reported the now classic $3 \pm 1.5$ C, and that was the end of it.

The subject got a boost at the end of the Carter administration. The synthetic fuels bill that was passed in 1980, out of concern for the high carbon concentration in coal-based gas and liquid, called for a study, again by the National Academy, of the "carbon dioxide problem." A committee, somewhat overlapping my earlier committee, this time chaired by William Nierenberg, studied the subject for 2 years and issued a book-length report in 1983 [8], a report somewhat at variance with another report released within the same month by the Environmental Protection Agency. Partly, at least, because the two reports differed in their assessments of seriousness and urgency, there was some media attention. Then mostly silence in the United States. Research in aspects of the subject accelerated but with little if any coordination.

[2] See Brooks (reference 7) for development of this argument as a "management attention problem."

It was a few hot summers that propelled the subject into scientific prominence in the United States, and the scientific "community" was not in advance of the general public and the media. There are now, to take an example, 200 American economists participating in greenhouse research; 15 years ago I think there were two. Some people think the subject is urgent, that a decade matters. Why didn't the subject get, 10 years ago, the attention it gets now? Was something missing, without which scientific attention could not be mobilized? Money, of course; foundation and government money is available now as it was not 10 years ago. But what may have been most lacking was imagination. Or perhaps coordination: so many disciplines are involved that scientists engaged in what was potentially "greenhouse research" may not have known there was a greenhouse phenomenon to which their work was pertinent, or, if they did, how to connect with the work of other disciplines remote from their own.

IIASA played a leading role in getting scientific attention, even policy attention, drawn to the greenhouse problem. Might it have done more? What is the next comparable issue that needs an imaginative systems approach to mobilize the world's scientific attention?

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