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Some Observations on Avoiding Pitfalls in Developing Future Flight Systems

Gary L. Bennett
Metaspace Enterprises
Emmett, Idaho; U.S.A.

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SOME OBSERVATIONS ON AVOIDING PITFALLS IN DEVELOPING FUTURE FLIGHT SYSTEMS

Gary L. Bennett*
5000 Butte Road
Emmett, Idaho 83617-9500

Abstract

A number of programs and concepts have been proposed to achieve breakthrough propulsion. As an cautionary aid to researchers in breakthrough propulsion or other fields of advanced endeavor, case histories of potential pitfalls in scientific research are described. From these case histories some general characteristics of erroneous science are presented. Guidelines for assessing exotic propulsion systems are suggested. The scientific method is discussed and some tools for skeptical thinking are presented. Lessons learned from a recent case of erroneous science are listed.

Introduction

Over the past few years a number of speculative propulsion/transportation ideas have been advanced which, if they can be verified, promise to revolutionize space transportation.[1-4] In addition, a question has been asked and some proposed answers given on the possible propulsion system(s) for unidentified flying objects (UFOs) or "flying saucers", if the existence of UFOs is accepted.[5,6] Researchers at the U.S. Air Force (USAF) Phillips Laboratory have proposed research into "... more advanced ideas ... [such as]... fundamental physics concepts which require basic research and/or substantial development to create some sort of breakthrough. These include vacuum zero point energy, energetic species (i.e. nuclear or electronic metastables), ball lightning, and various 'breakthrough physics' concepts. In addition, a number of new emerging technologies and popular ideas will be followed such as nanotechnology, above unity devices, and cold fusion".[7]

Separately, NASA has recently initiated a "breakthrough propulsion physics" program which "... implies discovering fundamentally new ways to create motion, presumably by manipulating inertia and gravity or by harnessing other interactions of matter, fields and space-time".[8,9]

*Fellow, AIAA

Given the speculative proposals and the interest in developing breakthrough propulsion systems it seems prudent and appropriate to review some of the pitfalls that have befallen other programs in "speculative science" so that similar pitfalls can be avoided in the future. And, given the interest in UFO propulsion, some guidelines to use in assessing the reality of UFOs will also be presented.

This paper will summarize some of the principal areas of "speculative science" in which researchers were led astray and it will then provide an overview of guidelines which, if implemented, can greatly reduce the occurrence of errors in research.

Some Case Histories of Errors in Science

This section will briefly describe several case histories involving errors in science: (1) N rays; (2) Davis and Barnes experiment; (3) polywater; (4) infinite dilution; and (5) cold fusion.

N Rays

In 1903, French physicist Rene-Prosper Blondlot claimed to have discovered that by heating a filament inside an iron tube containing an aluminum-covered opening one could see faintly illuminated objects better in a darkened room. Some of his early experiments were performed with pieces of paper which were barely illuminated by a glowing calcium sulfide screen or a lamp shining through pinholes. Since the heated filament inside the iron tube improved the viewing, Blondlot concluded that a new type of ray was being produced, a ray which was stopped by the iron but not by the aluminum. He called this new ray an "N ray" to honor the University of Nancy, where he worked.[10]

Blondlot discovered that certain objects could be made to store these N rays. For example, if a brick was wrapped in black paper and exposed to sunlight it would give off N rays when taken back into the darkened laboratory. Blondlot noted that if the brick was held close to one's head it made it easier to see the paper in the darkened room. Holding the brick near the paper had a similar effect.[10]

Blondlot reported that the N rays had some odd effects. For example there was no improvement in the effect of improved illumination if more than one brick was used. Loud noises (such as someone entering the laboratory) could spoil the effect. Heat increased the effect but Blondlot said N rays were not the same as heat. Blondlot also claimed to have found negative N rays, which he called N' rays that could nullify the effect of the N rays. It was necessary to spend some time in the darkened room to see the effect.[10]

Blondlot published a number of papers on N rays. Other scientists also published papers with about half confirming Blondlot's work.[10]

The American physicist R. W. Wood visited Blondlot to witness some of the N ray experiments. Wood watched as Blondlot used a large aluminum prism with a 60° angle to measure the refractive index of the N rays to two or three significant figures.[10]

When Wood questioned Blondlot as to how he could measure the position of the beam to within 0.1 mm when the slits in the Nernst filament were 2-mm wide, Blondlot replied to the effect "That's one of the fascinating things about the N rays. They don't follow the ordinary laws of science that you ordinarily think of".[10]

At Wood's request, Blondlot repeated the experiments; however, unbeknownst to Blondlot in the darkened room, Wood had removed the aluminum prism. Blondlot got the same measurements! Wood subsequently published this result, effectively ending the era of the N rays.[10]

Later some German researchers investigated how Blondlot had been deceived. They observed that in a darkened room it is difficult to see the paper so one is tempted to pass one's hand in front of the paper to see if the paper is being illuminated. The interesting result the German researchers found was that the hand could be "observed" whether it was in front of the paper or behind it. Langmuir has remarked that this "... is the natural thing, because this is a threshold phenomenon. And a threshold phenomenon means that you don't know, *you really don't know*, whether you are seeing it or not. But if you have your hand there, well, of course, you see your hand because you *know* your hand's there and that's just enough to win you over to where you know that you see it. But you know it just as well if the paper happens to be in front of your hand instead of in back of your hand, because you don't know where the paper is but you *do* know where your hand is".[10]

The phenomenon of accepting a false belief and then continuing to defend it in the face of information showing the falsity of the belief is not new. In a landmark study published in 1956 it was stated that "A man with a conviction is a hard man to change. Tell him you disagree and he turns away. Show him facts or figures and he questions your sources. Appeal to logic and he fails to see your point".[11] As this study demonstrated, showing someone unequivocal and undeniable evidence that a person's belief is wrong means "The individual will frequently emerge, not only unshaken, but even more convinced of the truth of his beliefs than ever before. Indeed, he may even show a new fervor about convincing and converting other people to his view".[11]

Davis and Barnes Experiment

Around 1930, two American physicists, Bergen Davis and Arthur Barnes conducted a series of experiments in which electrons from a hot filament were accelerated to match the speed of alpha particles being emitted from a polonium source. By carefully adjusting the voltage used to accelerate the electrons the experimenters claimed that they could cause the electrons to be captured by the alpha particles. The measurements were made in a darkened room by counting the number of scintillations on a zinc sulfide screen with a microscope. To save time, the experiments were focused on the voltages where it was calculated that the peaks should occur according to the Bohr theory. Davis and Barnes claimed to be able to achieve electron capture at each of the energy levels of the Bohr theory of the helium atom with measured accuracies of 0.01 volts.[10]

Irving Langmuir and Willis R. Whitney (then both at the General Electric Research Laboratory in Schenectady, New York) visited the Columbia University laboratory of Davis and Barnes and witnessed some of the experiments. They found that Barnes was not counting for a fixed two minutes as claimed and that he was ruling out some counts arbitrarily. When Langmuir secretly had the technician try a wider range of voltages Barnes got measurements that no longer correlated with the Bohr energy levels. Barnes had an *ad hoc* excuse for every criticism Langmuir raised about the way the experiments were being conducted.[10]

Langmuir, who was to earn the 1932 Nobel Prize in chemistry, subsequently wrote Barnes a 22-page letter giving Barnes all the data obtained by Whitney and himself "... and showing really that the whole approach to the thing was wrong; [Barnes] was counting hallucinations, which I find is common among people who work with scintillations if they count for too long. Barnes counted for six hours a day and it never fatigued him. Of course it didn't fatigue him, because it was all made up out of his head".[10] The next year Davis and Barnes admitted in a short article in *Physical Review* that they hadn't been able to reproduce the effect. They noted that the scintillations they were measuring were a threshold phenomenon.[10]

Polywater

In the 1960s and early 1970s reports from N. N. Fedyakin of the Kostrama Polytechnical Institute of the former Soviet Union and Boris V. Derjaguin of the Institute of Physical Chemistry of the Academy of Sciences of the former Soviet Union claimed there was a new form of water, later called polywater, that was more dense and viscous than normal water. Polywater, which was claimed to be formed in capillary tubes in an atmosphere nearly saturated with water, reportedly froze at -50 °C and boiled near 300 °C. Infrared spectroscopy showed that polywater produced a spectrum entirely different from normal water. Many papers were published on polywater and several theories were developed.[12]

As part of a study of polywater, Denis L. Rousseau and Sergio Porto, then at the University of Southern California, irradiated a sample of polywater with a laser to obtain a Raman spectrum. The laser turned the polywater into a black char, indicating that it "... was no polymer of water but more likely a carbonaceous material".[12] Whenever negative results like these were obtained, the proponents of polywater would always claim that the samples giving the negative results were contaminated but that their own samples, which showed polywater, were clean. Rousseau later showed that one could obtain the infrared spectrum for polywater from ordinary human sweat. This showed "... that polywater is not water at all but a product of organic contamination in the capillary tubes".[12]

Rousseau subsequently observed that "The polywater episode illustrates the loss of objectivity that can accompany the quest for great new discoveries. The quantities of polywater available were so small that many useful experiments could not be done. Many theories were put forward to describe the structure of polywater without even considering the thermodynamic difficulty of accounting for its very existence. Finally, definitive experiments showing high levels of contamination were done but not accepted, until overwhelming evidence showed that a new polymer of water had not been discovered".[12]

Infinite Dilution

In 1988 Jacques Benveniste of the University of Paris and his collaborators reported that water retained a memory or template of a molecule even when there should be no molecules present. This phenomenon is referred to as "infinite dilution" meaning that a biological effect is produced even when the "... biologically active solution is diluted so many times that no active molecules can be present ..."[12]

After Benveniste's paper was published in *Nature*, John Maddox, the editor of *Nature*, James Randi (a professional magician), and Walter Stewart (an experienced fraud investigator) spent three weeks in Benveniste's laboratory witnessing the experiments. When an elaborate series of double-blind experiments were conducted the biological effect was not measured. This committee of three reported "... that the original experiments were poorly controlled and that no effort had been made to exclude systematic error or observer bias".[12]

Many of the traits reported in the earlier episodes of erroneous science were present with infinite dilution. The effect was weak and independent of the causative agent. The counting was done visually and it was extremely difficult to do. When the control produced results at variance with the experimenters's beliefs the counting was redone. Negative results were overlooked. Sometimes experiments would not work for several months and one investigator seemed to be the best at making the experiments work.[12]

Rousseau has written that "Benveniste and his colleagues were not doing fraudulent work. They observed the effects that they reported. But they so believed in the phenomenon that they could ignore or reinterpret any questionable findings. In replying to the Maddox committee, Benveniste wrote, 'It may be that all of us are wrong in good faith. This is no crime but science as usual and only the future knows.' But, self-delusion is not science as usual".[12]

Cold Fusion

In 1989 two research groups in Utah announced that they had discovered cold fusion by means of simple electrochemical cells. Both research groups used heavy water although their salts were different. The heavy water would split into deuteroxyl ions (OD^-) and deuterons when a current was passed through the cells. What they hoped to achieve was to collect enough deuterons at the palladium cathode to cause them to pack so tightly that they would fuse at room temperature and release energy, a process normally requiring temperatures on the order of 10^8 °C.[12]

B. Stanley Pons of the University of Utah and Martin Fleischmann of the University of Southampton reported achieving enough cold fusion that the thermal output exceeded the energy input by 4.5 times. To explain away the absence of the neutrons which should have been present at a level sufficient to kill the experimenters they reported that "... the bulk of the energy release is due to a hitherto unknown nuclear process".[12] It was later learned that their electrochemical cell was not a closed system so they did not have a good heat balance. Moreover, their method of calculating the energy release was flawed.[13,14]

David E. Williams, the Thomas Graham Professor of Chemistry at University College London and previously a research group leader at the Harwell Laboratory of the U.K. Atomic Energy Authority responsible for that laboratory's attempts to verify cold fusion, has written about one staunch advocate of cold fusion repeating "... the common assertion that the excess energies associated with the electrolysis of D_2O with a Pd cathode are on the order of tens to hundreds of MJ/cm^3 and hence can only find an explanation in some phenomenon outside the chemistry of the system. In this he displays an ignorance of the experimental measurement and a naive belief in the significance of impressively large numbers. The great majority of experiments measure power; the large numbers are obtained by multiplying an (often small) power by a large time (the duration of the experiment) and dividing by a small volume (that of the Pd cathode). In comparison with the total energy applied to the electrolytic cell, the excesses are much less impressive, on the order of a few percent. More properly, in comparison with the power applied to the cell, the claimed excess power is often also small ...".[15]

Steven Jones of Brigham Young University and his collaborators found evidence of increased neutron production but nothing like the heat output reported by Pons and Fleischmann.[12]

Other researchers were unable to duplicate the experiments of the two Utah groups. The neutron emissions measured by Pons and Fleischmann were inferred from a gamma-ray emission spectrum that was more narrow than the resolution of their detector. The claim that tritium, one product of a deuteron-deuteron fusion reaction, had been found was later discredited when it was learned that tritium was a contaminant in the palladium electrode.[12]

As Rousseau has summarized it, "Cold fusion was doomed from the start when a race to be first took precedence over the desire to be right. Most measurements reporting nuclear effects from cold fusion were barely above the background noise, and extended periods of failed experiments afflicted even Pons's laboratory. The proponents of cold fusion attributed the failure to several causes: differences in the materials, the size of the electrodes, impurities in the electrodes, and low current density. The list goes on.

"Nuclear reactions, however, are very well understood. Any theory offered to account for the reported observations must postulate new nuclear processes that only occur in the palladium electrodes ... The investigators of cold fusion also ignored definitive experiments".[12]

The whole sorry episode of cold fusion, which the co-chair of the Department of Energy Energy Research Advisory Board panel on cold fusion, Professor John R. Huizenga, has termed the "scientific fiasco of the century", has been well documented in Refs. 13,14, 16-18. Suffice it to say that it is not a pretty picture but as Prof. Huizenga stated: "The cold fusion fiasco illustrates once again that the scientific process works by exposing and correcting its own errors".[13]

Despite all these problems the U.S. Air Force has considered studying (as noted earlier) "... a number of new emerging technologies and popular ideas ... such as nanotechnology, above unity devices, and cold fusion".[7] Some USAF personnel apparently foresee using cold fusion for satellite power and for fast acting thrusters for survivability. The payoffs are listed as (1) lower weight; (2) near limitless source of heat; (3) high reliability and operability; and (4) simplicity and robustness. The only technology needs identified were the scaling up of cold fusion and the development of specialized pumps, valves, and nozzles.[7] The fact that no reputable, objective scientist has been able to prove the existence of cold fusion seems to be beside the point! (Even NASA got in the cold fusion act briefly in response to the NASA Administrator's order that no nuclear power sources be flown again on NASA spacecraft. After researchers at Lewis Research Center were unable to make cold fusion work and mission planners at the Jet Propulsion Laboratory showed to the Administrator's satisfaction that there wasn't much sunlight in the outer Solar System he recanted his order against nuclear power although he does want a more sporty -- and possibly unachievable within current funding and schedule limits -- conversion system for the next generation of radioisotope power sources.)

As shown by the original hullabaloo over cold fusion and the more recent NASA activities followed by the proposed USAF program, an unfortunate aspect to bad science such as cold fusion is that it diverts time and funding from real science. Science writer Gary Taubes has written that "What cold fusion had proven, nonetheless, was that the nonexistence of a phenomenon is by no means a fatal impediment to continued research. As long as financial support could be found, the research would continue. And that support might always be found so long as the researchers could obtain positive results. In fact, the few researchers still working in the field would have little incentive to acknowledge negative results as valid, because such recognition would only cut off their funds. It promised to be an endless loop".[14]

Something like this has certainly occurred with thermionic reactor research in the U.S. where hundreds of millions of dollars have been spent yet no long-lived (>5 years), high efficiency (≥10%), high specific power (>5.5 We/kg) in-reactor-core thermionic system has been built in the U.S.[19-21] Still the studies continue, now with a focus on bimodal power/propulsion systems.[22] And despite the investment of over $500 million in today's dollars with no U.S. in-core thermionic reactor being built and meeting the aforementioned goals, General Atomics of San Diego, California was recently awarded a $5.4 million cost-plus-fixed-fee contract by the Defense Special Weapons Agency "... for the research, development, test and evaluation of advanced in-core thermionic technologies to support long duration space missions for national security purposes. Focus is on the advancement of thermionic performance rather than an overall system design improvement *since no specific mission has yet been identified on which to base detailed system requirements*"[emphasis added].[23] Given the end of the Cold War and the lack of military reactor missions coupled with the lack of any real progress in U.S. in-core thermionic research it is doubtful if there will ever be any real military system requirements but contracts will continue to be awarded in an "endless loop". Is this pathological science or pork barrel politics -- or both?

Symptoms of Pathological Science

On 18 December 1953, Nobel-laureate Irving Langmuir gave a colloquium on the subject of what he termed "pathological science", the science of things that aren't so. As Langmuir stated it, "These are cases where there is no dishonesty involved but where people are tricked into false results by a lack of understanding about what human beings can do to themselves in the way of being led astray by subjective effects, wishful thinking or threshold interactions".[10]

Based on his study of the Davis and Barnes experiment, the incident of the N rays and other early mistakes, Langmuir listed six symptoms of pathological science:[10]

- *The maximum effect that is observed is produced by a causative agent of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.*

- *The effect is of a magnitude that remains close to the limit of detectability or, many measurements are necessary because of the very low statistical significance of the results.*

- *There are claims of great accuracy.*

- *Fantastic theories contrary to experience are suggested.*

- *Criticisms are met by* ad hoc *excuses thought up on the spur of the moment.*

- *The ratio of supporters to critics rises up to somewhere near 50% and then falls gradually to oblivion.*

Working with more recent erroneous science such as polywater, infinite dilution and cold fusion, Denis L. Rousseau, at the time a Distinguished Member of the Technical Staff at AT&T Bell Laboratories, condensed Langmuir's six symptoms into two characteristics and added a third, which he believes to be the most important:[12]

1. *The effect being studied is often at the limits of detectability or has a very low statistical significance.*

2. *There is a readiness to disregard prevailing ideas and theories.*

3. *The investigator finds it nearly impossible to do the critical experiments that would determine whether or not the effect is real.*

In looking at the cases of pathological science presented in this paper it is clear that most of them are at the limits of detectability and they often were based on subjective visual observations. The fact that there may be no direct connection between the causative agent (e.g., number of hot bricks supposedly emitting N rays) and the effect (better viewing) is not seen as an impediment to the "new" scientific "discovery". News accounts of the advertised anti-gravity effect also place the effect at the limits of detectability.[1,2]

Cold fusion represents perhaps the most extreme example of concocting new theories to explain a poorly understood and poorly conducted set of experiments.[13,14] In contrast to the ready belief of the cold fusion proponents in the fantastic new physics invoked to explain their results, the author found it refreshing to hear from several of the original nuclear fission researchers (who were coincidentally meeting in a special 50th anniversary conference at the same time as the cold fusion fiasco erupted) that they were unwilling to accept their experimental results until all other avenues had been explored.[24] Would that other researchers had been as careful!

In none of the examples considered in the previous section did the researchers conduct experiments to determine if their results could be wrong. And in those cases where other researchers came to different conclusions they were criticized for having made mistakes or using bad samples or the wrong procedures.

Carl Sagan has written about people who make extraordinary claims, "The burden of proof is on them, not on those who might be dubious".[25] In short, if someone believes he/she has discovered cold fusion or anti-gravity it is up to him/her to prove it beyond a shadow of doubt. It is not up to the skeptics to disprove it. Unfortunately, as Sagan has observed pseudoscience operates just the opposite from normal science: "Hypotheses are often framed precisely so they are invulnerable to any experiment that offers a prospect of disproof, so even in principle they cannot be invalidated. Practitioners are defensive and wary. Skeptical scrutiny is opposed. When the pseudoscientific hypothesis fails to catch fire with scientists, conspiracies to suppress it are deduced".[26]

As Sagan has so eloquently put it, "I believe that the extraordinary should certainly be pursued. But extraordinary claims require extraordinary evidence".[25] To date the extraordinary evidence has not been reported for cold fusion or anti-gravity.

Guidelines for Assessing Other Exotic Propulsion Systems

One writer has pondered the question of what sort of propulsion system a UFO would have to have to match the reported observations of the motions of so-called flying saucers.[5,6] Even though people have seen strange things in the sky for centuries, the "Age of Confusion" about flying saucers began with the sighting near Mount Rainier by private pilot Kenneth Arnold on 24 June 1947.[27] Following Arnold's claimed sighting there have been thousands of reports of strange craft in the skies.[27,28]

Unfortunately, the sightings remain for the most part anecdotal and the photographs are generally suspect. Supposed artifacts have been shown to be of terrestrial manufacture. In short, while there remain some unexplained episodes, the vast majority of "sightings" are of natural phenomena or they are delusions or hoaxes.[25-28]

Astronomer Alan Hale, who is co-discoverer of Comet Hale-Bopp and director of the Southwest Institute for Space Research, has listed three basic principles as guides he uses in confronting beliefs about UFOs or other paranormal phenomena:[29]

1. *Extraordinary claims require extraordinary evidence.*

As an example of the kind of extraordinary evidence he is seeking, Hale lists "... the actual physical aliens themselves, where I and other trustworthy and competent scientists and individuals can study and communicate with them. I'd like to examine their spacecraft and learn the physical principles under which it operates. I'd like a ride on that spacecraft."[29] And he lists other things he would like to see and investigate directly.

Personally, I would like to see the UFO land on the Mall in Washington, D.C. and be subjected to a complete inspection using all the resources (scientists, engineers, technicians, equipment, etc.) at humanity's disposal. Like Sagan [25,26], I am highly skeptical about these reported aliens in UFOs since they never seem to contact any officials, they never demonstrate or leave any technology we don't already have and they never leave any messages that we don't already know.

2. *The burden of proof is on the positive.*

Hale demands that the one making the claim produce the extraordinary evidence to prove the correctness of the claim, noting that the burden is not on the skeptic to prove that the advocate is wrong. He goes on to state that "... you must prove your case by providing the direct and compelling evidence for it; you can't prove it by eliminating a few token explanations and then crying, 'Well, what else can it be?'"[29]

3. *Occam's Razor: If one is confronted with a series of phenomena for which there exists more than one viable explanation, one should choose the simplest*

explanation which fits all the observed facts.

Hale notes that people can make mistakes in their observations and that most people are not aware of the natural phenomena one can observe in the sky. Many people are not trained to observe what they claim to observe. People can be deceived by their preconceived notions and expectations and some people will create hoaxes. Hale asserts that "Taking all these undeniable facts together, the simplest explanation--to me, anyway--for the UFO phenomenon is that every report is either a hoax or is a mistake of some sort. If this explanation is incorrect, then you have to increase the sphere of undeniable facts; and for this, see points 1) and 2) above".[29]

Another "breakthrough physics" concept being studied is based on the belief that energy can be extracted from the zero-point fluctuations of the vacuum.[7] In searching for the origin of this idea, R. L Park of the American Physical Society wrote that "'The New Energy News' ... credits the idea to physicist Harold E. Puthoff and proclaimed him 'The New Energy News Theorist of the Year.' ... Puthoff's ideas are controversial; but he's accustomed to controversy. In 1972, at the Stanford Research Institute, Puthoff and Russell Targ were promoting psychic spoon-bender Uri Geller; five years later, they published 'Mind Reach,' a book about remote-viewing that inspired the CIA to invest in psychic espionage. Reportedly, Puthoff himself once sent his mind to explore the surface of planet Mercury".[30] Clearly, Hale's principles should be applied to this type of research!

Author's Note: For those not familiar with the *New Energy News*, it has been published by something called the Fusion Information Center which also disseminated information on cold fusion. This publication states that it is interested in "... papers ... covering both theory and practice of energy producing devices and systems such as cold nuclear fusion, rotating N-Machines, Solid-State energy systems, Magnetic over-unity machines, Tapping Space Energy (Zero-Point Energy), gravity control techniques, energetic transmutations (nuclear reactions), and other new energy research".[31] Those interested in some of the activities of Harold Puthoff, Russell Targ and the spoon-bender Uri Geller are encouraged to read *Science, Good, Bad and Bogus* by Martin Gardner.[32]

The Scientific Method

Physicist Alan Cromer has described science as "... the search for a consensus of rational opinion among all competent researchers ... The products of science give empirical proofs of its theories. Mathematics and experimentation provide powerful arguments with which to convince and persuade".[33] Cromer states that "Science is the heretical belief that the truth about the real nature of things is to be found by studying the things themselves".[33] Cromer also notes that the scientific way of thinking is not natural to humans; it is something which has to be learned.[33] Sagan has observed that "Science is a way of thinking much more than it is a body of knowledge".[25]

To study things requires the use of the scientific method. While there is no single absolute detailed process to be followed for all science, the American philosopher Morris R. Cohen has written that "The problem of how to get rid of illusion and see what truly goes on in nature requires that persistent and arduous use of reason which we call scientific method ... Scientific method is a systematic effort to eliminate the poison of error from our common knowledge".[34] In short, science is as much a process as it is an assembly of facts, but it is a process that requires assembling of the relevant facts (quantitative measurements) and the testing of hypotheses. It is a process that any scientist in the field should be able to duplicate in order to check claims of new discoveries.[25,26,29,32-35]

To aid in avoiding pitfalls in developing advanced propulsion (or exploring any new field), Sagan's tools of skeptical thinking are highly recommended:[26]

- *Obtain independent confirmation of the "facts".*
- *"Encourage substantive debate on the evidence by knowledgeable proponents of all points of view."*
- *Give little weight to arguments from authority.*
- *Develop and test more than one hypothesis in a fair and objective manner.*
- *Do not become overly attached to your own hypothesis.*
- *Quantify your observations wherever possible.*
- *Test the entire argument -- "If there's a chain of argument,* every *link in the chain must work (including the premise)--not just most of them".*
- *Use Occam's Razor -- when two or more hypotheses explain the data equally well, choose the simplest hypothesis.*
- *"Always ask whether the hypothesis can be, at*

least in principle, falsified. Propositions that are untestable, unfalsifiable are not worth much ... You must be able to check assertions out. Inveterate skeptics must be given the chance to follow your reasoning, to duplicate your experiments and see if they get the same result."

A useful guide in conducting scientific research is the National Academy of Sciences publication *On Being a Scientist.*[35]

Lessons Learned

In the concluding chapter of his book, *Cold Fusion: The Scientific Fiasco of the Century*, Professor John R. Huizenga lists 15 lessons from which we all may profit in conducting research. These lessons are [13]

- **Handling far-out ideas and claims**

Far-out ideas and claims should be presented first informally at a meeting of colleagues to address the hard questions. Where the work involves science or technology outside the advocate's main area of expertise the briefings should include experts from those areas. When all questions have been answered and all the experimental checks made one should present the results to other experts outside the laboratory or organization and then submit to the peer-review process.

- **Judging hypotheses**

One should avoid the extreme position of rejecting all previous work in the field just because one has obtained some anomalous result. If a hypothesis requires the belief in several miraculous occurrences then the hypothesis is probably pathological.

- **Premature publication**

Researchers should submit to the full peer review process to avoid being caught later with an unsound paper. Editors and reviewers also have a responsibility to ensure the technical soundness of a paper. Where there is some justifiable need for urgent publication the editor can always put a disclaimer on the paper noting that it has not been peer reviewed. (The author proposed something like this for speculative papers submitted to the annual Intersociety Energy Conversion Conference not only as a caution for other researchers but as a warning to potential investors.)

- **Publication by press conference**

The announcement of a new scientific discovery at a press conference should only be done where it is justified and where there is enough supporting information to back up the claimed discovery. Generally, it is far better and safer to "announce" the discovery through the normal peer review process.

- **Publication of primary data**

Researchers should publish enough of their primary data and experimental procedures to enable other researchers to check their results. If mistakes are later found these should be formally noted in the same publication that carried the original data.

- **Reproducibility in science**

Researchers should publish sufficient information about how they conducted their experiments so that other researchers can check their work. As Huizenga has written, "The foundation of science requires that experimental results must be reproducible. Validation is an integral part of the scientific process".[13]

- **Scientific isolation in research**

Breakthroughs in science generally are made by researchers who are fully knowledgeable in their fields and in contact with other researchers. In contrast, University of Utah officials claimed that the isolation of Pons and Fleischmann from both the traditional centers of fusion research and from nuclear scientists was what led them to make their claimed breakthrough discovery of cold fusion. Unfortunately, when their cold fusion results could not be duplicated by reputable, objective (and skeptical) scientists, cold fusion was dubbed another example of the "Utah Effect" (a term first used in connection with University of Utah Professor Edward Eyring's 1972 mistaken claim of discovering the x-ray laser).[13,14]

- **Control of information**

Researchers must be open with and willing to share their research data and experimental techniques. Free and open communication is central to the scientific process.

- **Secrecy in basic research**

Basic research is best conducted openly with the peer review process. If the research is done in secret the kinds of errors that afflicted so-called cold fusion can occur. Similar problems occurred when the former Strategic Defense Initiative Organization (SDIO) tried to develop a nuclear rocket code-named "Timber Wind" using a technology (particle bed reactor) that was highly questioned by outside experts. In that case people who had technical concerns about the viability of the concept were either ignored or denied further access to information on the program.[36]

- **Discovery by outsiders**

There seems to be a growing belief that only people who are not experts can make breakthrough discoveries because their minds are not clouded by "official" science. The facts are quite different--it is very rare that a non-expert makes a breakthrough discovery outside his or her field. As Prof. Huizenga has observed, "Most fundamental discoveries are made by persons intimately familiar with their research discipline because they not only know the subject matter of the field but also know the pitfalls and traps and have made many of the obvious mistakes".[13]

- **Lobbying before Congressional committees**

Lobbying before Congressional committees is contrary to the scientific process of peer review and it is particularly dangerous when the advocates are championing something like cold fusion which has not been confirmed. Not only is lobbying for unproven concepts damaging to science it wastes the country's limited research funds. Prof. Huizenga has estimated that "It has taken upwards of some fifty to one hundred million dollars of research time and resources to show that there is no convincing evidence for room temperature fusion".[13] Timber Wind cost the U.S. at least $139 million between Government Fiscal Years 1987 and 1991 largely on the basis of Congressional lobbying.[36] Thermionic reactor research has cost the country on the order of $500 million in today's dollars.[19] These monies could have been better spent on peer-reviewed space technology of more benefit to the country.

- **Funding large initiatives**

Large initiatives should be funded only when there is clear, objective, peer-reviewed evidence in support of the concept.

- **Patents and revenues from basic science**

If the concern is over protecting patent and intellectual property rights, the normal process is to verify the scientific results first, then file the patents and then announce the work. The process of announcing the results first with very limited information and no scientific verification was a key contributor to the cold fusion fiasco.

- **The press and basic science**

The press should explore claims of breakthrough science thoroughly making sure that the public is being given a true picture of what is claimed. The preferred process for publicly reporting new discoveries is to wait until the research paper has been peer reviewed and accepted for publication by a respected journal in the field. Using press conferences before complete scientific papers were accepted contributed to the confusion about and eventually distrust of claims of cold fusion.

- **The scientific process**

Claims of breakthrough discoveries should be made through the usual scientific process of peer review and validation through independent reproduction of the results.

Concluding Remarks

Advanced propulsion research must be continued because of the tremendous payoff it offers to our ability to conduct scientific, exploration, and commercial space missions. However, in our studies of advanced propulsion concepts we should be guided by the scientific method so that we can avoid the types of pitfalls that have ensnared other scientists in what Irving Langmuir has called "pathological science". Physicist Richard P. Feynman said it best in his minority report on the Challenger accident: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled".[37] Unfortunately, what has often occurred with pseudoscience is that "... for the survival of an unsuccessful technology, public relations must take precedence over reality".[14] If we ignore reality then everyone loses and our research field is damaged.

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