Robert W. Bussard's Last Interview

Dr, Robert Bussard's fusion breakthrough — fusion has finally arrived

Audio interview[1] by Tim Ventura, American Antigravity, published on October 14, 2007. Interview transcript by Mark Duncan, www.askmar.com, December 8, 2007. While efforts have been made to verify names, some are likely to be misspelled. Emailing corrections to mark@askmar.com would be greatly appreciated.

Introduction

In his final interview, the late Dr. Robert Bussard talks about many of the significant events of his long career such as IEC fusion, nuclear rockets, and the Bussard ramjet.

Born in 1928, Dr. Robert Bussard was known for his "Bussard Ramjet" concept, a modified fusion-drive starship christened in the 1960s by Carl Sagan and further popularized by authors such as Jerry Pournelle and Larry Niven. His career included tenure as an Assistant Director of the Atomic Energy Commission, and designer of the Nerva rocket (a government-sponsored project to develop a nuclear powered rocket for heavy-lift applications in the late 1960s.)

A founding member of America's fusion research establishment, he spent the last 20 years of his career developing the IEC Polywell fusion device that produced over 100,000 times the output of Farnsworth's original IEC experiments. In 2006, Bussard's Polywell design was awarded the Outstanding Technology of the Year Award by the International Academy of Science.

Bussard's Polywell is relatively small compared to tokamak designs. An 8-foot diameter reactor is projected to generate 100-megawatts, making it suitable for powering Navy ocean vessels and submarines. Furthermore, it has many applications for space missions, including spacecraft capable of reaching the moon in less than 8 hours time.

Mainstream Fusion Research

Tim: *I'm Tim Ventura of American Anti-Gravity and I'm speaking today with Robert Bussard, former assistant director of the Atomic Energy Commission and founder of Energy Matter Conversion Corporation. Dr. Bussard is one of the true pioneers of modern fusion research and joins us to talk about a new technology he has developed for cheap, clean fusion energy.*

I'd like to start out by asking about the state of modern fusion research. I think that most people are aware that modern fusion research is a collection of big dollar government and academic research programs, but I'm not sure how much people know about progress being made in this field. Could you describe for us the current state of fusion research in the United States and how much money this is costing us?

RB: Tim, this is a very complicated topic because controlled fusion research goes back to 1952 when Lyman Spitzer at Princeton University invented a machine he called the Stellarator to make controlled fusion. It was a classified program from than until 1956, when it was declassified at the Geneva Atomic Energy Conference because the Russians appeared and spoke openly about it. Since than there has been continuous government investment on a particular line of approach that was adopted by nearly all physicists of the Western World. To date, over $18 billion has been spent over the past 56 or 58 years and they are no closer to success than they were at the beginning except in the sense that they've learned more about why things aren't working as they wished they would.

The problem with most western fusion programs is that they are based on controlling and confining fusion ions by using magnetic fields. Unfortunately, magnetic fields don't really confine plasmas. The plasmas are combinations of equal numbers of negative electrons and positive ions. The positive ions make fusion. A plasma is a neutral thing overall made of negative and positive charges. Magnetic fields don't confine these plasmas, rather they constrain their motion to a predictable level if you manage to avoid instability, but they are not able to hold them in place

The fundamental physics problems and difficulties that plagues all of these Maxwellian local equilibrium plasma machines forces them to design machines of huge sizes. If you look at the public relations releases from the government over the many past decades, you'll see that these big toroidal tokamak magnetic donut things have

[1] Windows Media 10 version: www.americanantigravity.com/graphics/interviews/Robert-Bussard-Interview.wma — mp3 version at: http://www.nanos.org.uk/Robert-Bussard-Interview.mp3

become the size of small factories, costing tens of billions of dollars when they are scaled to the size that anyone thinks they might make net power.

These machines are not economical and don't do anything that electric utilities want (the utilities have been telling them that for 30 years). Despite this, these government programs continue because they are interesting and good science; even though they will not result in an economic fusion power plant.

Tim: *I think our troubles in the Middle East revolve around — have highlighted our need for imported oil, but I'm not talking about Iraq or Ben Laden — I'm talking about OPEC 1973 oil prices. Given that a lot of this research was born out of events that happened 30 years ago, I'm wondering what the time line is for the big government approach to tokamak style fusion?*

RB: I was the assistant director of the thermonuclear fusion division of the Atomic Energy Commission (AEC) from 1971 to 1973 when it was headed by Dr. Robert Hirsch. Dr. Hirsch is a very brilliant man who had earlier worked with Philo T. Farnsworth on the same thing that we are now pursuing. He had several assistant directors of which I was one. When the Arabs and the OPEC business occurred in the early 1970s, they astounded the world by arbitrarily raising oil prices. Since everyone believed Saudi was an energy problem, the AEC under Hirsch decided to capitalize on it and try to raise enough money to get fusion research really moving in the AEC. Up until that point, it had been running at a relatively small funding level split across the five national laboratories since the 1950s. Nobody was getting anywhere in particular, except in understanding the problems of confining neutral plasmas and their instabilities. We went to Congress and created a program that eventually reached something like $800 million dollars a year in 1970 type dollars, and escalated because we could say, "look, if fusion works, you don't have to keep using oil."

The problem of the Maxwellian fusion systems is that they all have to use deuterium and tritium (the second and third isotopes of hydrogen). Tritium is a radioactive material you have to manufacture by neutron capture. Lithium-6 is an enormously complicated material in an engineering sense.

But the reason they did this is that its the easiest, most probable way to make fusion between ions; and it is the only thing that can possibly work with a magnetic, Maxwellian equilibrium system. What we did when we raised the money to start the program in the early 1970s, the three of us that put that through, Dr. Hirsch, myself and Dr. Alvin Trivelpiece, said, "Look, lets get a lot of money to make the National Laboratories feel happy, so they can pursuit their own interests, at levels they are happy with, and we'll take 20% off the top and use it to study things that we really know should be done. The problem with this approach was that all three of us left within 9 months. The people who inherited the program thought it was all real and thought we should go ahead with magnetic Maxwellian tokamak fusion, and its been that way ever since.

Tim: *In 1995 you wrote letters to most of the physicists and government administrators in the hot fusion field as well as to influential members of Congress in the House and Senate saying that you as well as the other gentlemen had supported tokamak research in the 1970s for these political reasons. What sort of response did you get?*

RB: No response at all. We were saying that the program was completely derailed after we left, because nobody understood we were doing it to raise enough money to scrape some money off the top to try and do some real things, and it became a budget program. Harry Lidsky, a MIT professor, wrote an article in the MIT Technology Review, "The Trouble with Fusion."[2] The subject of his article was that when the program became large and budgeted, it ceased to become a fusion research program. Instead everyone focused on continuing the large budgets each year after year, so they could maintain their large scale laboratories. It's a human failing, people want things to stay the way they are, to grow and not blow them. When we left, that was it.

Tim: *You've painted a rather bleak picture for the conventional approach to fusion. Let's talk about something different, your technology. You've been working on a form of inertial electrostatic confinement fusion for many years now. Could you start by describing IEC fusion?*

IEC History

RB: Let's go back. It all begins in 1924 with Irving Langmuir[3] and Katharine B. Blodgett who wrote several papers[4] in the Physical Review on how to produce negative potential wells by having ions and electrons moving between concentric spherical, cylindrical, and slab geometries.

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[2] Lawrence M. Lidsky, "The Trouble With Fusion," MIT Technology Review, October 1983.

[3] Dr. Irving Langmuir won the Nobel Prize in Chemistry in 1932 for his work in surface chemistry.

[4] "Currents Limited by Space Charge Between Concentric Spheres," Physics Review, 23, pps 49-59, 1924.

Dr. Irving Langmuir

In the 1950s, Philo T. Farnsworth, the inventor of raster scan television, conceived a new way of using these negative potential wells. He was able to use spherical electric field negative wells to concentrate ions at their centers where they would make fusion. He filed very extensive 60 page patents[5] in the late 1950s that were like physics textbooks. He was a very ingenious man and than he proceeded to build some of these machines.

Philo T. Farnsworth

The way he went about making them was to construct spherical electrodes to form the potential well. Ions were than dropped into that potential well, enabling the ions to circulate back and forth like marbles in a well. They would roll back and forth; hitting each other, now and than at the center where it got denser and denser due to $1/r^2$ convergence. When the ions hit each other at the center, they either scattered or went back up the well, giving their energy back to the well. This process continued on average a thousand times, before a collision resulted in a fusion.

When a fusion occurs at the center, the fusion products are very energetic, leaving the system radially, flying out to the walls where they hit and they make heat. You could extract this energy using steam tubes in the walls, that would run steam turbines to make electricity. Alternatively, if the fusion particles are charged, you could put an electric grid out there and make direct electric conversion.

IEC fusion is a spherical colliding beam machine, as opposed to a Maxwellian mixed plasma tokamak machine. IEF fusion machines are completely out of equilibrium.

Farnsworth achieved these spherical wells by putting in spherical screen grids, back to back inside a sphere, and by biasing one internal screen grid to a high potential potential and the other to a negative potential, he could accelerate ions through the screens and to a focus in the center.

He had a young, post-graduate student, Dr. Robert Hirsch working with him. They build small 6 to 8 inch diameter machines that obtained world-breaking results with 10^{10} and 10^{11} DT fusion events per second. The key problem that Farnswell knew, and his patents show and disclose, was that they could never make net power because the ions had to go back and forth through the grids where they had a chance of hitting the wires of the grids and getting lost. There was no grid so transparent that it would allow a thousand transits without being hit. While these machines could never make net power, they did make interesting fusion output.

About the same time, three other people at Los Alamos Bill Elmore, Jimmy Tuck, and Ken Watson wrote a paper[6] in which they inverted the potential geometry, putting a positive voltage on the screen. They injected electrons that were accelerated by the positive screen, making a negative potential well into which you could drop the ions inside the screen. This eliminated the ions traveling through the screen, however the electrons continued to hit the screen. The electrons would have to make 100,000 to a million transits before a fusion occurred and that killed that idea, because you couldn't get net power because again there wasn't any screen so transparent that the electrons wouldn't eventually hit it.

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5 "Electric Discharge Device for Producing Interactions Between Nucleii," P.T. Farnsworth, U.S. Patent 3,358,402, issued June 28, 1966.

6 "On the inertial-electrostatic confinement of a plasma," William C. Elmore, James L. Tuck, and Kenneth M. Watson, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Physics of Fluids 2, 239 (1959)

So the existence of these screen grid systems allowed you to produce fusion, but not in any way that would ever let you get to net power. That was the beginning of all this. Dr. Hirsch who was a key developer of this technology with Farnswell, still has one of the machines on his desk in his office in Virginia.

Polywell

So what did we do that was different? We got rid of the screens! We realized that the key problem was losses due to hitting the screens. The only other way you could contain the electrons was with a magnetic field. That's a perfect good idea since while magnetic fields don't control neutral plasmas very well at all, they are great in controlling electrons because the electrons have very little mass. If you inject the electrons into a quasi-spherical magnetic field that goes towards zero at the center and a large field at the surface, the electrons will be reflected by the field and keep going back and forth, back and forth, never seeing a screen.

The loss problem is that you must find a way to keep the electrons from hitting the magnetic coils that produce the fields that otherwise confine them. So you've traded a problem that you can't solve — of losses from electrons hitting screens; for a problem that you can solve — designing magnetic coils and fields to minimize losses.

That's the focus of our patents and approach, having a quasi-spherical magnetic field into which you inject energetic electrons that are trapped inside of it, go back and forth and make a negative potential well. Pop ions inside, they never see any screens and walls, and let them all circulate until they make fusion.

Tim: *You're creating a negative potential well within a confined area that works a little like a thermos bottle. The negative potential well is the little well, and the only way for hydrogen ions to leave the bottle is to be converted into helium. But the reaction products automatically ejects it from the core. This sounds to me more like a fusion engine than a traditional reactor.*

RB: It is more like a turbo-jet engine in the sense that it is not a device that you ignite; rather it is a continuous dynamic through-flow machine.

- Electrons are injected in the front end to make the well.
- Fuel is added in the middle to be combusted, in this case, the ions that circulate and make fusion.
- And the fusion products go out the back.

While you can call it a continuous loop machine, it is really a power amplifier; it is not an ignition machine.

Tim: *This machine does pure DT fusion with no radioactive output?*

RB: No, no, if the machinery works as it is supposed to, it will work with any fusion fuel, DD, DT (we'd rather not use due to the radioactive tritium), D^3He, or pB11. It just has to be driven at different voltages for these different kinds of fuel. DD is the simplest and cheapest since deuterium is available from seawater and every glass of water you drink. One 1/6000 of every gallon of water is heavy water (deuterium oxide). The problem with DD fusion is that it makes a neutron for each fusion, so it is not a non-radioactive fuel. It makes as many neutrons as when you run a pressurized water nuclear reactor, but it has the virtue that when you turn it off, you don't have any fission products, which is the problem of fission reactors.

In the long run, what you want to do is run pB11 fusion since this reaction makes three charged He atoms with no neutrons. It is the only non-neutron releasing fusion reaction we know. These ions will all leave at high velocity from the center of the machine. You can put grids outside the machine that are biased to slow them down to make electricity directly without using steam turbines. It is an interesting long range prospect, a clean, non-neutronic nuclear power that is directly converted to electricity with nearly 80% efficiency. That's the eventual goal.

Tim: *What level of power output do you anticipate seeing from this technology, like a successful final prototype?*

RB: The next major step in our development program that we hope to find support for is a $150M to $200M 100 MW demonstration plant. It is not a commercial plant. You might design a commercial plant to be 100 MW, or you might design a 1,000 MW central supply plant. On the other hand, smaller sizes seem be desirable to the utility people because it reduces the transmission line losses and makes for a more distributed grid. But I don't think it makes much sense to build a commercial plant much smaller than 100 MW. In the long run, you might design something to run a 18-wheeler truck, but this would be like a third generation, using pB11 fusion, but that is a long way off.

Tim: *How does the price tag compare for this, watt for watt with one of the big tokamak projects?*

RB: We've looked at this over the years, doing studies of what we think our plant costs and would look like. Our conclusion is that the cost of electrical power would drop by a factor of two for a thermal system running steam turbines.

With DD fusion, you'll still have some of the steam driven infrastructure and you're going to have to put the fusion reactors into pits just like fission reactors.

The advantage of DD fusion is that it makes for an easier retrofit into an existing power plant. You just cut into its steam lines, and cut in the fusion. You no longer have the cost of the fuel oil or coal. The fuel cost alone is an important portion of the cost of electricity particularly for natural gas and oil fueled power plants.

An even larger power plant cost reduction would result by going to pB11 fusion plants that use direct conversion. These plants have little of the conventional infrastructure of traditional power plants.

Tim: *Your project has been underway since 1986. How much progress have you made since than?*

RB: We've had twenty years of small scale research funded by $21M of government money that enabled 200 thousand man hours of technical people working in the laboratory during which we have constructed 15 different versions of these machines. We have laid out, defined and understood the scaling laws for 19 different critical physics issues.

We've solved each issue, one at a time, in a long and tedious process. This was because our funding was always very small compared to what we needed. While both we and the Navy knew that our funding was insufficient, larger amounts would have become visible to the Department of Energy, who would have complained about it. The political situation was such that they could only fund us at a low level, and they asked us, "can you do anything with this small amount of funding?"

So we worked with this limited funding, with the result that it took 20 years, and the above mentioned time and effort, but we did finally succeeded in solving the last basic physics problem in the final tests we did in 2005. All the basic physics is done, we're ready to do engineering development now.

Tim: *Was there any political motivation to discontinue your funding?*

RB: No, I don't think so, I don't think that there is any conspiracy theory here. The reason our funding died is not because the Navy did anything, but rather because of the Iraq war. The Iraq war budgets have been consuming everything in sight in Washington and when it came time for the budget process for fiscal 2006, the total Navy R&D budget was cut by 26% across the board. One of the things that was cut was the Navy Energy Program. We were a victim of that. We were a little pimple, down in the noise of that thing, but we died along with it. We had some friends in O&R that kept us alive for 9 months and that was it.

Last Minute Success

Tim: *After they pulled funding, I understand that you kept running tests up until the very moment that power was shut off. You had some promising results that resulted from subsequent analysis of your final tests.*

RB: No, it wasn't the power being shut off. We were looking at our budgets. We had to pay leases on our lab space, we had to commit to yearly leases and we couldn't do that with the little budget monies that were left. We had a plan where we had to close down by the 1st of November 2005 and start getting rid of all of the equipment since there wasn't any way to carry it past the end of the calendar year.

But in spring 2005 we ran some tests on a big machine called WB-5 that turned out to illuminate some things that we should have seen ten years ago and didn't, and when we finally understood what that meant, we realized we had missed a critical point in the whole problem of electron losses, and we quickly designed and built a last machine called WB-6, very different in its shape and detailed configuration.

We tested WB-6 in September and October 2005 doing low-power electron loss transport tests. But we were approaching November 1st and we hadn't tested the heavy fusion conditions yet. I said, "But we have to finish this," so we kept on working past this shut-down date. On November 9th and 10th we ran the machine four times, producing DD fusion at a rate 100,000 times higher than had ever been done before by Hirsh and Fansworth. We realized by measurement that we had finally solved the electron loss problem.

WB-6

Tim: *You really created fusion in the lab than?*

RB: We've been doing that in the lab for some years now, but always with high electron losses. We finally figured out why and solved the electron loss problem. On November 11th we tried it again, but the hasty construction of the machine resulted in a short in the magnetic coil that caused it to arc and melt down. We didn't have either the time or money to rebuild it. On the following Monday, November 14th, we started shutting down the lab. This took six weeks to finish, after which everything disappeared. We didn't even know we had the results we had obtained for a month until December when we reduced the data. We looked at it and said, "Oh, my Lord, look at what we've done! It actually worked, it finally worked, the last piece is there."

Tim: *While your project was funded by the Navy, the other big source for funding is the Department of Energy.*

RB: No, no, no, no. You have to understand. The Department of Energy is running down the road of magnetic Maxwellian local equilibrium machines with huge budgets to keep their national laboratories alive. They not only have no interest other than that; they have an active antipathy to anything that might be small, quick, cheap and compete with that approach. It is important as Larry Lidsky of MIT said to keep the big budgets alive; to keep funding these places at $2M a day even as we speak.

Tim: *You're looking at popular support. You've continued your research as a non-profit, what you might call a people's fusion.*

RB: We're looking for support from any source we can find. The investment community is one, but is not necessarily the optimum one. It would be nice if the Navy could find its way clear to renew our funding, to finish the contract we have, that has $2M unfunded in it. I don't know if that will ever happen.[7] But it finally occurred to us that if the people of this country want to solve the problem of oil wars, energy conflicts, acid rain, pollution, excess gasoline prices, and global warming, this is the way to do it. It will work.

If people want to do it and be partners in doing it, than there are a lot of people in America who care, I think. If we can get the message to them, maybe they will want to support it. So we formed a non-profit, charitable R&D organization with no stockholders, nobody is going to get rich from stock growth, just to do the R&D job for the net power plant that is the next step. We have this non-profit organization that allows tax deductible contributions, so if we obtain sufficient funds, we'll be able to restart the work. The way to do this is to go to our web site, www.emc2fusion.org.

Mobile Applications

Tim: *I'd like to ask about mobile applications for this technology. Would it be potentially possible to scale it to fit in an aircraft or maybe even a car?*

RB: Years ago, we looked at what it would take to scale down a pB11 clean machine. We couldn't figure out even with a 3rd generation system, which involved using certain kinds of interesting physics with compression issues in the center from instability drives; how to make anything much smaller than the size of a 18-wheeler truck. You could certainly build it to drive locomotives, I don't know about airplanes. It is basically an electrical energy producer and I suppose you could drive airplanes.

You could certainly build rocket engines that would make ground to orbit transit a hundred times cheaper than anything else, but I'm not sure that constitutes an airplane. It is a horizontal takeoff to LEO (low earth orbit) vehicle.

Tim: *For the automotive applications, you could use the fusion energy as the means for generating hydrogen to power them, not as a direct fuel source.*

RB: We proposed putting a pB11 system in a 18-wheeler to make an 1 to 2 MW electric plant. It's more power than they have had and its an easy way to go.

Tim: *There's been a lot of buzz recently about hydrogen in the automotive world and I'm wondering how this technology might help us migrate from fossil fuels to hydrogen fuel?*

RB: IEC fusion can make electricity very cheaply and therefore you can do electrolysis to produce hydrogen at a lower cost than by any other conventional means. The problem with the hydrogen economy is that it takes more energy to make the hydrogen than you get back from burning it. It is a net loser. The only way that the hydrogen economy works is if you can find some way to make the hydrogen cheaply.

For mobile fuel, a better solution is to make pure anhydrous ethanol at 35 cents per gallon using a fusion powered steam generator, compared with the $3.00 to $3.50 per gallon that it costs with today's corn to alcohol processes. At 35 cents per gallon, oil companies could sell it at 90 cents per gallon and everyone would profit. The small third world countries where sugar cane is grown would suddenly have a lot of new income.

Tim: *The big three auto makers have been hurting for years from competitive import autos. Given the price tag that you've been talking about for these fusion generators, might it not be cost effective for them to invest in fusion to thereby secure distribution for the next generation of America automobiles?*

RB: Well, I don't know who would do that. My impression of corporate America is that it is driven by six month accounting practices, with people are looking at the near term bottom line. Nobody in the American manufacturing world is interested in ten year payouts.

If we are going to get this thing running commercially, we need five years to build a demonstration plant, and another five years to be able to deploy things that can be

[7] On August 21, 2007, the Navy refunded the project. The WB-7 and WB-8 machines are being developed and tested in Santa Fe, NM.

retrofitted on a commercial power plant. There is about a 40 year half life to displace all the other existing energy sources throughout the world, but that will happen. Historically, when you made the transition from wood to coal it took 40 years, and from coal to oil, the same thing. Why? There is a lot of infrastructure you're going to have to displace and people want to get their investment money out of it. It isn't evil and there isn't anything bad about it, it is just the way things work.

Tim: *You also gave a presentation at Google not too long ago, discussing the possibility of building this device for less than the cost of their annual power bill. Can you tell me about how that went?*

RB: Oh, we had a good time. I was very impressed with Google and its people. It is a wonderfully interesting, very dynamic place. I was invited there to speak, I don't know quite how it all happened. I know that the man who discovered our work took it to Larry Park who said, "I'll have the man come up and give a talk." I never met him or the founders, but I had a good time and gave a talk that I thought was interesting to them. I didn't go to Google to seek their money because I didn't think that was practical, there are in a totally different IT world. But it was fun, anyway, and it turns out that they put it on the web[8,9] where it has gotten over 117,000 hits, so people are looking at it.

Tim: *Is the availability of fusion fuels a limiting factor?*

RB: No, deuterium is one part in six thousand. It is inexhaustible, found in all water. There is a ten billion years supply. And boron, if you do pB11 fusion, boron is the 10th most common element in sea water. There are already processes to extract it cheaply. There is enough boron in the ocean to last us a billion years. They are cheap, essentially free fuels that can't be controlled by a cartel.

Thoughts on Alternative Approaches

Tim: *What are your thoughts on alternative nuclear theories? There are a lot of concepts that are not easily quantifiable such as cold fusion, bubble fusion, or Dr. Fujiaro's claim that it is possible to generate neutrons. Do you have any thoughts on this?*

RB: While I have read and thought about them, I'm not highly familiar with them. There are many ways that one can make small amounts of neutrons that have no possible way to go beyond low levels. Cold fusion is one of them. Indeed in lattices, you can make fusion reactions occur, but you can't ever make them occur at a level of any interest in the sense of power or the power industry. Steven Joness at Brigham Young University was working on this long before Pons and Fleischmann and it was perfectly good microphysics.

With respect to bubble fusion, I'm not so sure that really is that effective, but it has its small effect like everything else like it. There are little oddities like that in the world that can make a few neutrons but they don't scale and you can't make them go anywhere.

Tim: *Dr. Ruggero Santilli says that he is working to validate Rutherford's hypothesis that the neutron is a compressed hydrogen atom. He claims he is creating and detecting neutrons in the lab by running an electrical arc through hydrogen gas.*

RB: That sounds like the German scientist (Ronald Richter) in the 1950s who got funding from Perón in Argentina to study fusion. I just don't think that is going to be real. The thing is that there is a lot of little gadgetry around that people look at. But when you examine them, they are all mixed Maxwellian plasmas that when they are supposed to be magnetic field confined, you are in real trouble because you are not going to get there.

Tim: *Why, because the magnetic field won't confine them?*

RB: No, with the plasma particles you can't do anything other than DT fusion because you can't do pB11 fusion in an equilibrium plasma; the radiation losses from Bremsstrahlung radiation simply overwhelm everything else. The only reason you can do pB11 fusion in our machines is because it is completely out of equilibrium. The electrons at the center are cold, the ions are very hot, if you want to look at it that way. Since the electrons are cold, they don't radiate.

Tim: *For nearly 20 years, there has been a riff between supporters of hot and cold fusion. Given the slow progress being made in both of these camps, I'm wondering if there is anything to be learned between the creativity and innovation of the cold fusion crowd versus the academic rigor that comes out of hot fusion?*

RB: I don't know what to say about the small scale stuff, only that I don't see any of it as having any hopes of growth or doing anything useful in a commercial global power sense. There is great and interesting microphysics, but I don't know what you mean about learning from each other. The tens of thousand of people that have been spending $18 billion dollars over the last 56 years on magnetic confinement fusion are all locked into that particular world of physics. Their entire mindset is

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[8] A video of this talk can be found at http://video.google.com/videoplay?docid=1996321846673788606

[9] A transcript of the Should Google Go Nuclear?, November 9, 2006 can be found at http://www.askmar.com/ConferenceNotes/Should%20Google%20Go%20Nuclear.pdf

there, they don't even have a history about thinking about other things.

Tim: *I thought an interchange of views would help them change their their mindset.*

RB: Why should they? They are getting $2M a day!

Tim: *That's an excellent point! A growing number of people like myself are becoming increasingly disenchanted with the dogmatism in both hot and cold fusion. Innovative concepts like IEC fusion and vortex fusion plasma don't fit into either category.*

RB: For almost of these things, when you examine their fundamentals, you find that they are mixed Maxwellian plasmas. This means you'll never go beyond DT fusion and if they are magnetically confined, you'll never get to net power. The fundamental physics limits you. You can make all the stories you want but it doesn't work.

The only way you are going to get there is by a non-equilibrium driven system that goes back to electrical engineering of Langmuir and Farnsworth of the 1930s and 1940s.

NERVA

Tim: *I'd like to touch on another key area which is space research. In the 1960s you played a pivotal role in the NERVA (Nuclear Engine for Rocket Vehicle Applications) nuclear rocket program. Can you tell me about that experience and what you learned from it?*

RB: I invented the program, really. I wrote a paper on nuclear rocket propulsion in 1953 when I was at Oak Ridge National Laboratory. I based some of it on work done earlier by Howard Cipher, Arthur Rook, George Gamow and Nick Smith at John Hopkins in the late 1940s and by people at North American also in the late 1940s and by a very fine paper by Tsien Hsue-Shen (who later built the Chinese ICBM) and a book on nuclear energy that came out of MIT. I thought I could put together a definitive paper[10] that would have a lot of nuclear calculations in it, including Carol Mills work at Oak Ridge, and show by system analysis that nuclear rockets would out perform chemical rockets for heavy payload missions for long range and interplanetary missions.

That seemed to attract the attention of the Air Force and its science advisory boards. The result was the start of the national nuclear rocketry program in spring 1955 at Livermore and Los Alamos, and my leaving Oakridge and coming to Los Alamos. During the course of the NERVA program, we built 17 reactors and ended up with a 250,000 ton thrust engine that could be cycled 40 times on and off. We had a perfectly brilliant program that was technologically successful. We ran hydrogen through graphite cores at very high temperatures, all carefully controlled that gave specific impulses 2.5 to 3 times higher than anything you could obtain from chemical propulsion.

NERVA Rocket Engine

The original idea was to use NERVA as a second stage rocket on ICBMs carrying weapons. That mission was dropped due to the bombs getting smaller and improvements in the rockets. The program ended up being controlled by NASA who intended to use it for a 1978 manned Mars mission.

Although the NERVA program was very successful, the program fell flat due to internecine political wars between the chemical and nuclear rocket communities, the budget office, and between Livermore and Los Alamos. Along came the Vietnam war and that sort of killed everything. The program vanished and went away. Fifty years ago, we had nuclear rockets that could take people to Mars! It is a long story which is best recounted in a book on the history of that program by James Dewar called *"To The End of the Solar System: The Story of the Nuclear Rocket."*

Tim: *If NASA were to deploy NERVA now, how much of the 1960s experience and technology would still be applicable?*

RB: I think it would all be applicable. All you would have to do is resuscitate it. Most of the people who did it are either retired or dead. But the technology is not hidden, it is in reports that people could easily resusci-

[10] Journal of Reactor Science and Technology (classified), R.W. Bussard, December 1953

tate it if you spent a little time and money on it. I don't see NASA doing it because its budget is hammered into the ground by the Iraq war. Everything R&D is being hammered into the ground.

Tim: *Do you think that technological progress since than would make such a space propulsion program even more feasible?*

RB: I don't think you need to go much beyond what it was. If you just rebuilt the one we had and started there. There's a lot of new ideas that have been around that haven't been proven in a reactor test. I think you should start by building what you know how to make and go from there. I think we already know the directions of improvement, and we already know how far you can improve it with modern materials. You should be able to go up to 1250 seconds I_{sp} instead of 850. Everything gets vastly better when you go to 1250, you can open the solar system to human transport if you want to revive that program. But that is going to be a program that takes time and money, and NASA doesn't have any time and money.

Tim: *How much time and money do you think it would require for a program like that?*

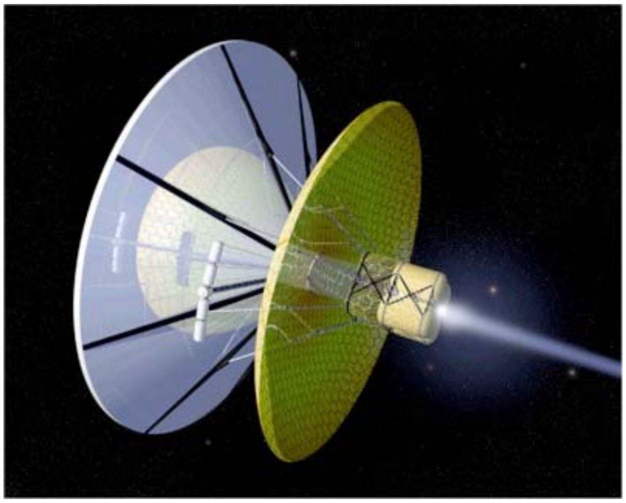
RB: I think it would take half the NASA budget for about ten years.

Tim: *So about $7 or $8 billion a year.*

RB: Yeah, I think so. But than you'd have a real fleet nuclear powered rockets that could carry people anywhere in the inner solar system, at least out to Mars or probably the moons of Jupiter.

Bussard Interstellar Ramjet

Tim: *Now in terms of other solar systems, Jerry Pournelle and other science fiction writers adopted the Bussard interstellar ramjet as the means for traveling between solar systems. Could you tell us about the origin of this concept and how the science fiction community picked it up?*



Artist Conception of Bussard Ramjet

RB: Well, that's a different story entirely. It occurred to me one night at dinner back in 1960. The idea of traveling between the stars, people have looked at that for years, looking at rockets and anti-matter rockets, one thing and another. But as long as you do it with rockets, you have the problem of having to carry all your rocket fuel on board and accelerating all the fuel you haven't burned. Lots of papers were written on it by very brilliant people such as Larry Steinger, Bob Cleaver and so on.

It occurred to me, why bother to carry the fuel when the hydrogen fuel is sitting out there in the spaces between the stars? That's the fuel that the stars run on! All you need to do in principal is collect the hydrogen between the stars as you fly, and magically put it into a fusion engine that can run on it, which the stars do, although they are rather large, using the fusion engine to run the ship.

So you fly along, scooping up the hydrogen and putting it into an interstellar ramjet. I did the mathematics for the physics constrains and it turns out that it works out very interestingly. It tells you the engineering conditions you have to achieve, mass per unit area of scope, and so on and so forth. In principal, it looked like this solved the problem from the standpoint of the physics.

I published a paper[11] on interstellar ramjets in 1960. Apparently that paper caught the attention of Jerry Pournelle, Larry Niven and other people in the science fiction writing community.[12] And I didn't even know that. Ten years later I got an invitation from Jerry to speak at a Nebula award dinner. And I said why? And he said, we're all using your ramship. And I said, you are? I didn't know that! So I went and gave the talk.

Of course, the engineering is virtually impossible today. But give us a 100 years of advanced engineering and it may be possible. There was a key feature missing and Dr. Daniel Whitmire, an astronomer at the University of Southwest Louisiana solved that. The problem is that the reaction rate for hydrogen - hydrogen fusion is very, very small. You have to do certain strange nuclear things to make it go. He found a way to enhance it by 10^{16}, wrote a paper on it[13], and made it all very practical.

[11] Bussard, R.W., "Galactic Matter and Interstellar Flight," Astronautica Acta, 6, 179 (1960)

12 The Bussard interstellar ramjet was featured in "Tau Zero" by Poul Anderson, "Orbitsville" by Bob Shaw and "A Deepness in the Sky" by Vernor Vinge.

[13] Daniel Whitmire, "Relativistic spaceflight and the catalytic nuclear ramjet", Acta Astronautica, 2, 497-509 (1975)

Spaceflight and IEC Fusion

Tim: *Well, what about your current IEC technology? How difficult would it be to deploy it for space travel?*

RB: Well for that, we wrote eight papers in the period from 1993[14,15,16,17] and 1994[18,19] to 2005[20,21,22]. We were under an 11 year embargo from the Navy not to write papers on our physics, publish or attend conferences. But they didn't care if we wrote papers about space flight. We said, if we had an engine like this, what could we do with space flight? So I wrote papers on various aspects of engine design for space flight propulsion that were given at international and AIAA conferences.

Fusion enables a spectrum of engine systems that outperform any competitor by a factor of a thousand. You can either have a thousand times the specific impulse at the same thrust and weight ratio, or get a thousand times higher thrust to weight ratio at the same specific impulse.

Everything changes when you apply this engine system to any solar system mission:

- Single stage transit to Mars in three weeks with a 20% payload.
- Transit round trips to the Moon in 24 hours.
- $25/kg to low earth orbit versus today's $5,000/kg.

Everything becomes totally different if you can ever get this engines built which would take another 10 or 15 years and another $5 to $7 billion dollars.

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14 "The QED Engine System: Direct-Electric Fusion-Powered Rocket Propulsion Systems," Robert W. Bussard, Tenth Symposium on Space Nuclear Power and Propulsion, January 20, 1993, V.271, pp 1601-1612.

15 "Inertial-Electrostatic-Fusion Propulsion Spectrum: Air-Breathing to Interstellar Flight," Robert W. Bussard and Lorin W. Jamesson, 1993, Journal of Propulsion and Power, Vol. 11, No. 2, pp. 365-372.

16 "Fusion-Electric Propulsion for Hypersonic Flight," by H.D. Froning, Jr. and Robert W. Bussard, June 28-30, 1993, AIAA/SAE/ASME/ASEE 29th Joint Propulsion Conference, Monterey, CA, AIAA 93-2611.

17 "The QED Engine: Fusion-Electric Propulsion for Cis-Oort/Quasi-Interstellar (QIS) Flight," 44th Congress of the International Astronautical Federation, October 16-22, 1993.

18 "Design Considerations for Clean QED Fusion Propulsion Systems," by Robert W. Bussard and Lorin W. Jameson, 11th Symposium on Space Nuclear Power and Propulsion, Albuquerque, 9-13 January 1994.

19 "From SSSTO to Saturn's Moon: Superperformance Fusion Propulsion for Practical Spaceflight," by Robert W. Bussard and Lorin W. Jameson, 30th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, June 27-29, 1994, AIAA 94-3269

20 "System Technical and Economic Features of QED-Engine Drive Space Transportation," Robert W. Bussard, 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July 6-9, 1997, Seattle, WA — AIAA 97-3071.

21 "Aneutronic Fusion Propulsion for Earth-to-Orbit and Beyond," H. David Froning, Jr. and Robert W. Bussard, Space Technology and Applications International Forum, January 15, 1998, pg. 1289-1294

22 "System/Subsystem Engineering Interface Considerations and R&D Requirements for IEF/QED Engine Systems," Robert W. Bussard and H. David Froning, Jr., Space Technology and Applications International Forum, January 15, 1998, pg. 1344-1351.

Helium-3

Tim: *There have been buzz recently on mining the Moon for Helium-3. I'm wondering what your thoughts are on that concept?*

RB: I don't think it is practical or necessary. There is no questions that there is Helium-3 on the Moon and that you could mine it and bring it back to the Earth at some enormous cost. But it is a completely unnecessary thing to do. While there is no Helium-3 on Earth, if you have a fusion reactor that can run on DD, half of the fusion reactions produce Helium-3. You can pipe the Helium-3 out of the fusion vacuum system and feed it back into the machine and burn it as D+Helium-3. You are manufacturing your own fuel as you go. So why would you go to the Moon if you have a DD fusion reactor that produces Helium-3?

Tim: *This piping almost sounds like a turbo-charger?*

RB: This is for a ground power plant, really. I wouldn't try and do this in a spacecraft, why bother? You don't want any neutrons in a spacecraft reactor, you're going to use a p-B11 reaction instead. In a D-Helium-3 fusion reactor, you're going to produce lots of neutrons, so you're going to need significant shielding. While the D-Helium-3 fusion will reduce the neutrons levels by a factor of 10, 20 or even 40; you'll still get lots of neutrons! The point is that you don't need to go to the Moon to get Helium-3!

Summary

Tim: *I guess I should reiterate to the audience that it sounds like you've made a fundamental fusion breakthrough.*

RB: Well, we think so. After 20 years, we've finished the basic physics that allows us to go on to engineering development. This means control systems, fuel systems, and all things that make the hardware work. Of course, I'm sure that there is some more physics that we will discover along the way.

Tim: *Your web site is at www.emc2fusion.org and donations can be made at the New Mexico Community Foundation.*

RB: There's a big button on the web site, and when you click it, it goes right to the New Mexico Community Foundation donation page.

Tim: *Well, I'd like to wrap things up by saying thank you yet again for a remarkable interview and asking if you have any thoughts in closing?*

RB: Well, just that it would be nice if we get off the fossil fuel business, stop energy conflicts and clean up the planet. This is the only way I know how to do it.