How Does Basic Science Defend America?

DOC DAUGHERTY: What will the customer, in this case the military, buy?

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STEVE KOONIN: The web browser.

DOC DAUGHERTY: The B2 was in fact driven by a basic science issue of computational electromagnetics.

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ROBERT KUHN: But do you have to justify basic science with the national security look to it?

STEVE KOONIN: No, science is about one's curiosity of the world, as someone once said, people observe the world and they tell a story about it, and that's what science is, all right? And that's a basic human drive. It turns out that we are able to use a lot of the discoveries of science to do technology, whether it's for economic good, or for national security, or both. But the science is something that is so beautiful and is such an intrinsic part of being a human being that you want to support it just because people are people.

ROBERT KUHN: It makes us what we are in our society.

STEVE KOONIN: Look at the wonderful pictures from other planets that we have, or the wonder that we have about the earth around us, that's science.

DOC DAUGHERTY: Only very, very small fraction of all basic research impacts defense in the classic sense, right. The larger fraction of it impacts national security in the broader sense, okay? And yet there is tons and tons and tons of basic science that goes far beyond that, medical science, psychology.

STEVE KOONIN: But even those have some impacts in national security.

ROBERT KUHN: What are some good examples of weapons systems that have been based on basic technologies?

DAVID HERRELKO: All of them. You go back to 20s and 30s, true pure basic research quantum theory, and that obviously comes up through the boys with the first transistor, integrated circuits, everything that follows, feeds a thousand fields. A more simple way when talking to the masses is that the basic research in the 60s, the development and testing in the 70s, the production in the 80s, and the people of the 90s cascaded together to make Desert Storm possible where you saw precision guided weapons going through. And it was all of those things and a group of people that waited 30 years for the maturing.

STEVE KOONIN: So the pipeline takes at least 30 years to go.

DAVID HERRELKO: Sometimes over a thousand.

STEVE KOONIN: Sometimes very short.

DOC DAUGHERTY: Well if it's basic science, if it's researched, if it's a productive discovery that defines the beginning of the pipeline. And in military systems you might say someone has demonstrated technology that has the potential to be applied to a defense problem, right, if you say that's the beginning, and I think we have pretty concrete evidence that it's probably in the 30 year category.

STEVE KOONIN: Although there are outstanding examples contrary to that, I mean nuclear fission is probably the most outstanding example, discovered in 1939, applied first in warfare in 1945.

DAVID HERRELKO: And I know generals that'll say, "now do that every time."

STEVE KOONIN: Of course, okay?

DAVID HERRELKO: I want that every time, deterministic predicted, I want to see the result on time, schedule it.

STEVE KOONIN: Sure, you can't make basic science work that like that, nor can you make the development part work like that.

DAVID HERRELKO: If you can't I'll find somebody who will, I'll give him the money. That's what they say.

STEVE KOONIN: You can argue, if you know the path so well it's really not a disruptive technology because in fact it's more or less a simple extrapolation from where you are now.

DAVID HERRELKO: I think our war fighters don't welcome disruptive technologies.

STEVE KOONIN: I understand.

ROBERT KUHN: Why?

DAVID HERRELKO: They're disruptive, the military people, by definition, have to be conservative within a framework. We have to train our people to use the weapons they have and if we give them a Mark IV, Mark V every week, we don't have a trained unit good to go. And nobody wants to send out people with disruptive technology that we're not ready for. Simple example, Islamabad, we're fighting against the Africans, or the Brits were, and a new technology was fastening the bullets into the boxes, it was screws. They were retreating, they had to pop the boxes, they couldn't, because it took too long to unscrew the box. So the military is very cautious about new stuff.

STEVE KOONIN: There are also social reasons, unmanned aerial vehicles area a very good example now, all right, we've started to see the beginning of it with the Predator and Global Hawk, but in fact you don't get medals, or at least not yet for flying unmanned aerial vehicles. And so these parts of the Air Force really want somebody in the plane. Another good example is why do you have four people in a tank, okay. And if you ask the tankers, it's because in fact there's an extra man there because when the tank breaks down you need somebody to help pull everybody else out. And in fact you could probably get by with four fewer people in a combat system. So, there are these social issues, that's the way we've always done it, a vested interest, and so on.

ROBERT KUHN: Who are the principle players in the relationship between basic science and national defense, and how do they work?

DOC DAUGHERTY: Well defense laboratories would like to capture a major piece of that, I think that they represent a stake holder.

ROBERT KUHN: Like Livermore, Los Alamos San Diego.

STEVE KOONIN: I think the universities are an important piece of this, but there are some parts of this pipeline that are not well done at the universities, I mean once it gets to the point of designing systems and so on properly, the national laboratories are an industry which is the other major stakeholder. But the really basic science and the very beginning of technology development does belong in the universities.

ROBERT KUHN: How does the academic community interact with the Defense Dept.?

STEVE KOONIN: There are two ways, one is that there are grants from the Defense Advance Research Projects Agency, for example, the Office of Naval Research, other

parts of the Dept. of Defense that fund basic research, they fund graduate students, post ocs, professors, equipment and so on. And then there are some universities that manage laboratories, Lincoln Laboratories at MIT, for example, is a good example of a Defense oriented laboratory embedded in a university.

DOC DAUGHERTY: But there are other stakeholders as well. Industry, obviously which lives off the, the contracts is a stakeholder in both the development aspects, competing to have the system that is preferred. And in the production where the management, costs, schedule, control becomes the issue, in fact delivering reliable, supportable, on time, in quantity, adjustable rates under the presence of varying budgets and changing threats.

DAVID HERRELKO: Industry as stakeholder, yes, but we can't ask them to do the basic research, we really can't.

STEVE KOONIN: I would agree, nor can you ask the universities to do this kind of mission driven, on time, on schedule, on budget sort of activity, that's just not what universities are good at.

ROBERT KUHN: Can basic science be held to a specific time line?

STEVE KOONIN: Basic science, no.

DAVID HERRELKO: I would say, no, it can't.

STEVE KOONIN: No, not at all.

STEVE KOONIN: Science is a hit and miss kind of thing very often, you'll strike out 50, 70 percent of the time but, you know, that 30 percent of the time that you hit something makes it all worth it.

ROBERT L. KUHN: And you can't predict it in advance.

STEVE KOONIN: You can't, it's a creative enterprise, you know, it's like how many great symphonies are you gonna write in the next five years if you're a composer, you can't predict like that.

DAVID HERRELKO: On the other hand, something wonderful that science does that very few other organizations do is blind peer review of documents. There is some really rigorous wire brushing given and brutal beatings that people take before they can publish because other men of science care enough to really work.

STEVE KOONIN: But parts of the defense establishment would do well with that kind of peer review, it does not take place as often as you would like in the government.

ROBERT KUHN: Do you agree with that?

DAVID HERRELKO: I think so, I think that it's very difficult in the military in a hierarchy to communicate face to face when every third word of the subordinate thinker is "sir."

STEVE KOONIN: Also, classification is also a problem, it's hard to get peer review when things are classified at various levels. That's why it's very important, I think and, you know, I will say unabashedly, I'm one of these, there are people who have the academic experience and credentials, but also have invested time and effort to get to know the national security problems. And it's very useful to have people at that gray area.

ROBERT KUHN: Doc, let's look at a specific program that industry would develop, which may be a 20 year program. How do you target specific basic sciences to be part of that?

DOC DAUGHERTY: It takes on average 15 plus years from the time a program is conceived until the time that program has its first operational system in the field, it's the average number. So you can say, if you're considering a new system, you can look at the stuff that you have in the laboratory and you can sort of predict 15 years into the future what's going to be available. And then the question is, what will the customer, in this case the military, buy. And so there's this natural evolutionary tension between the technology and engineering community which is predicting what you could make, and the operational military saying, what would I do with it, and what do I need. And we're actually shifting today from a, from a period where the military describes requirements, and then the systems are built to those specific requirements to a place where the systems are being conceptualized as capabilities to be able to do a spectrum of things.

ROBERT KUHN: Lets take some examples of that.

DAVID HERRELKO: We don't need war fighters telling us what angle of dangle for a particular thing underneath an aircraft, they shouldn't be telling us what metals should be used to mount a bracket on a plane.

STEVE KOONIN: Right, I want to put that ordinates on that target with that precision.

DAVID HERRELKO: Even better, I'd like them to say, I want that target to be disabled for at least a day.

STEVE KOONIN: Oh, even better, right.

DAVID HERRELKO: Even better, it may not be ordinates, it may be directed energy. They may not like the answers but if we have that broad guideline, we can generate from this incredible wealth of technology. There's basic science again, it creates many options, so when they say, "I need this effect based capability," we can say, "well, you can do it with boron, there's titanium.

ROBERT KUHN: Now who's doing this, we have the military, we have the defense, we have the academic community. Who is defining the need, and who is doing the work?

STEVE KOONIN: You know, at that level, that sort of brainstorming that you were just talking about, that probably takes place in the national laboratories. I want to come back to the B2, which is a wonderful system, and you should feel very proud that you had a role in that. But it also is a great example of how the basic science gets built up ultimately to provide a truly revolutionary capability. To do the B2 you had to understand electromagnetic scattering, you had to understand aerodynamics.

ROBERT KUHN: Which give it the stealthy…

STEVE KOONIN: Which gives it the stealthy character. You had to understand the propulsion, how the engines worked in order to reduce the signatures associated with the engines, as well as build an airplane that would fly.

DOC DAUGHERTY: But I'll point out that one of the major differences between the first Stealth aircraft, the HEP blue or the F1117 faceted derivative and the B2 was in fact driven by a basic science issue of computational electromagnetics.

DAVID HERRELKO: That's right, and that's the computers.

DOC DAUGHERTY: You were, in fact not able to compute a closed form solution, or even a good numerical solution to curved body refraction, reflection and conductivity.

ROBERT KUHN: Which made it invisible to radar.

DOC DAUGHERTY: Because what they were able to compute, the solution to the faceted design…

ROBERT KUHN: Faceted design is…

DOC DAUGHERTY: The F117 is built of flat plates.

DAVID HERRELKO: Looks like a gemstone.

DOC DAUGHERTY: It's got flat plates and edges every place. And the solution of that was…

DOC DAUGHERTY: …solvable from a computational perspective.

DOC DAUGHERTY: And the result was that people at that time understood that curved surfaces were probably better, but they could not predict the performance accurately enough to have confidence in it to be able to fly to spec.

STEVE KOONIN: Those equations that you were solving, of course Maxwell's equations, which comes from 120 years ago, very basic science.

ROBERT KUHN: And that was fundamental science with seemingly no practical application at the time.

DAVID HERRELKO: And you can't really vector the basic research scientist to a goal 30 years down. If you told the inventors of the laser that the chief reason that they should go do that is to make CDs for music for kids, it never would've happened, it never would've happened.

ROBERT KUHN: Is national security synonymous with weapons systems, or broader?

DAVID HERRELKO: It's broader.

ROBERT KUHN: What dose it include?

STEVE KOONIN: Well these days, defensive measures associated with detecting explosives, associating with biometrics, knowing who is who, for example, personal identification, ports of entry, scanning cargo containers, nothing to do with weapons systems, but very important these days to defensive missions. We also don't mount a very large standing army, and consequently rely on technology and a particular standoff technologies as we go into combat situations.

ROBERT KUHN: Which are more dependent upon the science.

STEVE KOONIN: Which are much <u>more</u> dependent on it.

DOC DAUGHERTY: There's a whole spectrum of conflict that science and technology applies to. I mean at the one end you have global nuclear war, at the other end you have petty theft, you know, in the middle you have religious warfare, which could be internal. The question is, where, where is the American public focused in terms of their concern,

and what is the relative consequences of the risk compared to its probability, and so the investments need to be focused on the places that have both the high consequence and the high probability of recurrence in science and technology, and basic research to boot works across that entire spectrum, from explosive detection, as Steve was pointing out,, you know, there are five or six major technologies that come out of science that are being applied to explosives detection. The Quadrapole Magnetic Resonance, which doesn't work for explosives that's in a steel can, because you can't detect it.

STEVE KOONIN: You can't see the radio waves inside.

DOC DAUGHERTY: But, using several neutron exitation, right, you can potentially detect what's in it, characterize it reasonably well. X-ray, today we're using x-rays in many different forms as imaging mechanisms, and using mathematics as the underlying basic technology.

DAVID HERRELKO: Which came from where?

DOC DAUGHERTY: Which came out of basic research.

DAVID HERRELKO: Absolutely, whether it was to take the twinkle out of the stars so that we could figure out the difference between a real cosmic body in space dust, or whether it was to try and penetrate triple canopy jungle and see a tank, there's a lot of spin-off to the medical industry, and then we export that stuff. And I think we're always going to be an open society where our basic research information almost always is available to everyone.

ROBERT KUHN: People criticize that, but in fact by having that we attract more and more scientists to our systems and have then the critical mass of scientists here in order to do other things.

STEVE KOONIN: And you make the science go faster because there's this great exchange among the disciplines. You know, one thing that people don't appreciate is the fact that these very transformative systems that we have, the global positioning system that is now used by everyone. This was the result of a 30 or 40 year poll starting from basic science, and then going through to this very tangible system. So these things don't happen by accident, they start with the basic science.

ROBERT KUHN: Let's go beyond weapons systems and talk about the internet and cyber security, which his, I think we would all agree extremely important to our new sense of national security.

DAVID HERRELKO: I had my first email address while I was at MIT as an undergrad. Of course very limited communication, and nobody had the slightest idea that

the killer app of all killer apps would be email to the pedestrian, not what they wanted it for.

STEVE KOONIN: But a later killer app was, in fact, the web browser, which came out of basic science, there was a guy who was trying to orchestrate data among a high energy physics collaboration on multiple sites, how can I access that group's data files when they're half way around the world, and he built the browser.

DAVID HERRELKO: What is wonderful about all this is what we now have with the world wide web was built by loyally disobedient people. If a typical old school military thinker had planned this and poured ten times the money in, you would've had a structured, unscalable system, where each person when they signed on had to identify by name every person that they might want to talk to. But instead we have this wonderful chaotic system.

STEVE KOONIN: But, that makes security considerations a very difficult thing to manage.

DAVID HERRELKO: I'm glad to have that problem.

STEVE KOONIN: There's another interesting mode of interaction between science and national security. For example when submarines started to have a broad reach through the ocean, I would guess probably late 40s and the 50s. We started to get much more interested in the science of oceanography, and we discovered currents, thermoclines, all the things that make the ocean go, similarly when aviation got up to the point where you could get up to the jet stream, people discovered the jet stream, they didn't know that. So, understanding the natural world because of military operational capabilities is another way in which the military has fed back into science

ROBERT KUHN: Not deliberately, but it's really a spin-off.

STEVE KOONIN: Yes, and great throes of data, for example, we've had classified satellite systems doing surveillance since the early 60s, there's an awful lot of environmental data that those satellites have picked up serendipitously, and mining that now is a very interesting activity that scientists are doing.

DOC DAUGHERTY: Well the naval acoustic data off the offshore sonar data is now being used by the marine science to listen to a lot of stuff that they have not been…

ROBERT KUHN: Some of that was said to be hurting the eco environment and killing the whales, is that true?

STEVE KOONIN: I think if you look at that objectively there is very little evidence for that at all. And it's a wonderful experiment to look at how the oceans are changing.

DAVID HERRELKO: I think spin-offs are an anecdotal way to tell stories, and the military and NASA and everybody on earth loves to say that their algorhythm is the one that's now letting us get higher resolution in mammograms. Everybody is on that train taking credit for it, in fact success has a thousand fathers.

DOC DAUGHERTY: There's another piece of that, is that you have scientists who are very narrow, appropriately so.

ROBERT KUHN: And scientists who are even narrower.

STEVE KOONIN: Matt Kabrisky said you really only have one great choice in life is, you can be narrow or you can be shallow.

DOC DAUGHERTY: But it's important that you have some people who are a little bit less narrow, and some people who are, in fact, shallow. In many cases it's the leadership who have, some say rank time IQ equals a constant. But at the senior level…

DAVID HERRELKO: I'm shallow and proud of it.

STEVE KOONIN: And that's okay, I mean my choice was to be shallow, but the issue was to be able to grab onto the source of the narrowness that has the depth that is needed to be able to point it or call on it or find the relationship that together could be integrated…

STEVE KOONIN: All of that technical management is making the connection between the right kind of narrow people to make something interesting.

DOC DAUGHERTY: And that's middle level that we really, there aren't very many people that do that very well.

ROBERT KUHN: When shallow works, I think that means breadth and being able to understand different areas, in fact that's needed.

DAVID HERRELKO: I'm worried about a cargo cult behavior that I see amongst some of our scientists when I say, how can we better champion better science and win an appropriate share of the funding that's needed? And the answer that comes back, it'll always be anecdotal, you can't predict. And I remember after World War II on Funwatu just south of Fiji, the cargo cultists sat there, and out of straw and bamboo they recreated air fields, recreated little airplanes with propellers, and they would light up lights at night hoping that the great metal birds would come back with the ice cream and the Hershey

bars, as if, if we keep doing what we used to do, the magic will still happen. And I guess my concern is, I believe the contract between the American public and basic science is fundamentally changing. I believe that from the time of post World War II, when we were infatuated with technology, and got a kick in the butt with Sputnik as well, we knew science was good for the country, that an investment in science would pay off in a great way so we would never again blacken the skies with 19-year-olds in a bunch of rickety air frames. And the belief was the scientists were wise and could choose. I'm not so sure that same contract is true any more.

ROBERT KUHN: Is there a cynicism in the country?

DAVID HERRELKO: No, not cynicism, but a fundamentalism, take your pick of any religious stripe you want, and there are a lot of people who are not only a-scientific, but anti-scientific.

STEVE KOONIN: Which is also ironic given the increasing impact that science and technology on all sorts of everyday life. So, what the cargo company needs, let me pick up on your metaphor for a minute, is a priest who, you know, he's got the radio calling the guys with the plane in the back room, he understands what's going on, but let them build the bonfires out the front.

ROBERT KUHN: That'll repeat the behavior.

DAVID HERRELKO: But you know, in fact the stakes are higher, I think the pace of technology and innovation happens all the time, I remember when Ursted discovered that electricity through a wire could bend a needle. The military applications happened very quickly in the form of minds controllable, Morse with his Morse code happened pretty quick, it's even quicker now, and the consequences are devastating when you talk about toxins, when you talk about nuclear things. So if we have n uninformed electorate, if we have people who are schooled in a way where they are not allowed to engage on these issues, if we don't raise our kids math and science to their full potential, we're going to lose them.

STEVE KOONIN: Often the political process doesn't want to hear about the science at all, and you can point to many examples in the present situation, whether it's stem cells or global change and/or levels of toxicity and so on. People just don't want to hear about it, never mind the facts.

DAVID HERRELKO: Well I praise industry, industry is trying hard to help hook up with schools in their immediate areas, they're putting a good deal of money in those programs and their people's time, but it's sticking fingers in the dyke.

STEVE KOONIN: And it's not that everybody has to grow up to be a scientist, it's just that you want people to have some appreciation for the fact of the pipeline that we were talking about.

ROBERT KUHN: You can't be an informed citizen in today's world without significant understanding of the science.

STEVE KOONIN: Because many of the scientific issues impact on societies.

ROBERT KUHN: In all other areas.

DAVID HERRELKO: And the more of a Farm Club of fourth graders that we really carried through the 8th grade and keep them interested, the better a crop we're going to have and the more effective will be our basic science.

DOC DAUGHERTY: Anti-science has done so much to damage the educational environment, that in fact poisons the ability of these young people who are otherwise potentially candidates from being interested.

DAVID HERRELKO: I remember when the Interstate 405 at Santa Barbara, all five lanes, or whatever it is, shut down southbound because a truck had dumped bags of ferrous oxide, they were bags of rust. But they got the men with the masks and they're out there cleaning up.

STEVE KOONIN: You know, and I think that's a uniquely US phenomenon in society, I think if you go to Japan or you go to Western Europe or even Eastern Europe you will not find that same sort of anti science bias.

DAVID HERRELKO: And the enrollment in science is down, and the number of students willing to go for graduate degrees in science, which is where you're really starting to use the upper part of your brain, is down.

DOC DAUGHERTY: And the economy is so good, at least with the past five or six years, you know, that was sucking grad students out into industry and so you weren't creating the new generation of professionals.

STEVE KOONIN: What's most important is to have a vital scientific base that continues to discover new phenomena, and maybe more importantly train people and provide, as you said at the very beginning a kind of platform on which you can build these technologies as they're needed. And it's so important given our social, economic and political tendencies that we have that technology base if we're going to continue to have a secure nation.

ROBERT KUHN: Well, things are changing, we're here talking about in essence the military, industrial, academic complex that maybe started in World War II or before, reached its peak during the Cold War, we're now in a different era. Do the institutions have to change, as well as our thinking?

STEVE KOONIN: Of course they do, the circumstances are changing. Homeland defense is now a major issue on everybody's table. Look at, you know, that's not only about the military, the military never operates within the US, or never did, you now have to mix up the military with law enforcement, for example, intelligence agencies whose main charter is overseas are now worried about how do we pick up intelligence within the US. And so I'm sure we have to change the government organizations, the way business operates has changed. It used to be large monolithic companies, Gm, GE, IBM, and so on, we now have a whole host of smaller companies that grew up from the startup mania of the last four years.

ROBERT KUHN: Or broke off.

STEVE KOONIN: Or broke off.

DAVID HERRELKO: If you want to talk about things beyond military contributions, to me basic science has made possible all kinds of wonderful inexpensive photography and satellite dishes and Satcom and if there's a trouble spot in the world independent of war, if there are atrocities alleged, why don't we just airdrop in cameras and small dishes and let the people there show the world.

STEVE KOONIN: Or you order up Icanos images commercially, right?

DAVID HERRELKO: I have to go back to national economy. The United States invests a tremendous amount in basic science, and we should, and we often incorrectly measure percentages with other smaller countries. I'm not sure it's a linear thing, but I do believe that we can, with confidence keep investing in basic science, even if other nations harvest from it because we are all so agile and adaptive and tremendously aggressive in grabbing that stuff and taking it to market. And only in an open society where the basic science is available can we continue to live and work that way.

ROBERT KUHN: And we maintain the critical mass of personality, resources and institutions.

STEVE KOONIN: That's why it's so important to have students coming from abroad, for example, we're only 300 million people on a globe that's six billion people, if we can collect the smartest half a percent of people from around the world and educate them here, get them to understand American values and society, boy that's such a great thing.

DOC DOUGHTERTY: There's a lot of work to be done, and happily the future is long.