Maj. Gen. Larry Stutzriem, USAF (Ret.):

Well, good morning. Good morning, ladies and gentlemen, and welcome to our panel on the quantum imperative. I'm Larry Stutzriem, and I'm the Director of Research at the Mitchell Institute for Aerospace Studies. Quantum technologies may soon enable innovations and applications ranging from inertial navigation to quantum communications. China is taking note. They're aggressively funding quantum research, apparently seeking to pursue unique asymmetric advantages over the United States. Still, there are numerous questions on the prospects of the various quantum modalities and applications. What is, and where is, this technology today? Hopefully, today's guests can clear up the fog that surrounds this cutting-edge technology topic.

Let me introduce the panel. First, we have Dr. Michael Hayduk, Deputy Director of the Information Directorate at the Air Force Research Laboratory. In this role, he's responsible for $1.8 billion budget, and he leads over 1,200 people. He also coordinates AFRL's quantum information science portfolio, organizing lines of effort across six technical directorates for C4I applications.

Next we have Tanner Crowder, Dr. Tanner Crowder. He's a policy analyst at the Office of Science and Technology Policy National Quantum Coordination Office. We're also privileged to have Chester Kennedy. He's an executive advisor to the Inflection leadership team, formerly called Quantum. Inflection specializes in using the neutral atom modality as the basis for applied quantum technologies. In his capacity, he advises Inflection on doing business with all agencies of the US government, and he's working to standup manufacturing capability for the unique components required to produce quantum-enabled systems. Okay, last but not least, of course, we have our very own Heather Penney, Senior Resident Fellow here at Mitchell Institute, and she is laser-focused on cutting edge defense policy issues with a focus on leveraging the critical advantages of air and space power. She's a fighter pilot and her tactical call sign is Lucky. Lucky Penney.

She will be completing a Mitchell study on quantum this fall, so please stay tuned and look forward to that. With that and the panel introduced, I'd like to go ahead and just dive into some questions right away and for the panel, all of you, and we'll start here and work on down. I think quantum is often perceived as being constantly 10 years out, but people would be surprised that quantum technologies are common and around us today. The kind of quantum that we're discussing today is what experts in the field describe as the third quantum revolution. I want to ask our panel one by one. Can you explain what is different about today's quantum technology. Doctor?

Dr. Michael Hayduk:

Sure. Thank you very much and it's a huge honor to be on this panel today and to be able to talk about Quantum, but shout out to the opening ceremonies and the first session. Wow. It just really shows why we're here and what we do and the purpose behind it. With quantum, just a little primer there since I'm kicking it off. Quantum mechanics goes back a hundred years or so. You mentioned some of the technologies that are out there now because of quantum and they use quantum, but we're continuing to move past that. We're really, when you think about quantum, if I could stress anything, it's a difficult subject and you start looking into it's hard to really grasp and understand it compared to other technologies, but you're really at the fundamental levels of nature. So things we learned about way back in high school, physics and chemistry really come to apply here, such as photons, ions, electrons, protons, et cetera.

Being able to control, manipulate, and use those single particles is where we're at today, and that has led to new things such as we're going to talk extensively about today, sensors and computing, communication systems, networking systems, improved clocks, all those things are really being driven today. A lot of it has to do with the engineer in me at heart is really fabrication techniques and supply chain management. We will get into those things as well, but being able to not only be at the fundamental level of nature, but being able to control it is where we're at. Being able to have things like dilution refrigerators, high speed electronics, vacuum systems, all those things play into it and really why do we see this driver? It has a lot to do with the worldwide investment that you mentioned earlier, and we're really at an important stage now with Quantum, and we'll get into this as we're looking to move quantum out into the field, but definitely an exciting time to be in the field.

Dr. Tanner J. Crowder:

To echo what Mike said, yes, quantum is hard. We have known about Shore's algorithm for 30 years now, and it's just today that we're actually starting to see some of those technologies that might help us implement Shore's algorithm actually be conceived and developed at a very fundamental level, still at the hello world stage of quantum computation. But for things like quantum sensors, we've been using quantum sensors for decades in the form of atomic clocks in GPS navigation and MRI, and as we move towards the control of single particles and even into entanglement between single particles, which really lets us leverage the power of quantum information, we'll see even more precise sensing technologies, precise control, precise metrology, and as we actually start to miniaturize and take these technologies from the lab to the field, we will start seeing what kind of real challenges there are for field ability and commercialization.

I think that's starting to be where we're thinking about today. It wasn't that long ago that in a RIMPAC demonstration that atom interferometry was put on a ship and we were actually able to do gradiometry on a ship for a month. That's a huge step forward, I think. I think as we see, as we look toward fielding these technologies and seeing what they can actually do, can they be used for monitoring groundwater recharge as they've been proposed to or the precision navigation and timekeeping? What kind of control do we need for that? We'll really begin to see what we need to do to actually field these technologies and bring them to market.

Chester Kennedy:

I think that's some really good explanations, hard to add to that. But our founder often talks about that we're entering the revolution where quantum comes into the kitchen. What he means by that is that it becomes such a part of our everyday life that we don't even recognize it anymore as being quantum. Right? It's like the transistor and it takes me back, and I know I'm dating myself, but it takes me back to when I bought individual transistors to build electronic projects when I was studying electrical engineering many years ago. I still remember the astonishment when the professor one day proclaimed that someday we would have 10,000 transistors in a single integrated circuit, and what in the world would we do with 10,000 transistors all put together in an integrated circuit?

Of course, we come fast-forward from there, and there's probably not anyone in this room that doesn't have 30 billion transistors in their pocket or in their purse, in their cell phone. I think that's the real exciting part about it. All the other applications that you've heard mentioned here today, those things are real. They're coming. But what's more exciting to me is the things that we haven't even envisioned yet because we're just at that stage of where we were with the transistor in the seventies and eighties.

Heather Penney:

This third quantum revolution moves us beyond exploiting the behaviors that we know quantum matter does to the point where we can now control, manipulate, and measure and actually move those behaviors in ways that are useful to the war fighter. That's really important to understand about this third revolution in terms of what quantum can do for us. But it's important that senior leaders understand the science behind it so that they don't fall victim to the science fiction of this quantum revolution. Then as war fighters, we need to begin doing the work understanding how do we match those capabilities, that technology to our capability gaps. As we begin to talk about sensors, inertial units, timing, RF antennas, how can we use this new quantum capability to our advantage in ways that can not be countered by the Chinese? That, I think, is what's really important.

But to really access this third quantum revolution, we also have to focus on fabricating the classical everyday technologies, miniaturizing lasers, how do we get the form fit so we can get the function out of quantum mechanics? We have to ensure that we don't allow this belief that quantum is continuously 10 years into the future and commercial will someday bring that to the war fighter. Because to be honest, many of the capabilities that we will need in scale don't have the same scale of demand in the civilian marketplace. The DOD, again, needs to be a leader in bringing the quantum revolution to the war fighter.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Yeah. Well, let me stick with that a bit. I'll direct this question at Dr. Hayduk and you, Heather, when people think of quantum as a field, they'll jump to a couple things, quantum computing or maybe encryption-decryption. But quantum information science and technologies have a lot of different applications relevant to national defense. Could you walk us through some of the major lines of effort in quantum technology with respect to national defense?

Dr. Michael Hayduk:

Sure, great question. Let me step it through the way the Air Force organizes our quantum information science program and really focusing in on applications, and I think that'll be most helpful here. We organize our program across AFRL and we have six of the nine technology directors actually working some form of quantum information science research and development. It's very pervasive across the entire enterprise. We're working on things and we put them into kind of four buckets, timing, which would be improved clocks, sensors which we heard a little bit about here as well. We combine those clocks and those sensors. Really when you think about losing GPS in denied or contested environments, what alternative forms of timing, navigation, and positioning do we have? Alternative P&Y. Bringing those technologies together are kind of the basis of those two.

Then we move on to networking, kind of think of this as quantum communications, but we're really going beyond point to point or data links and really looking at what Tanner had mentioned, entanglement distribution and how we're able to harness not only single particles, but being able to connect very disparate particles together to really give us new capabilities that we haven't even thought about. Being able to develop quantum networks. First and foremost, in our opinion, certainly in the Air Force of interest would be security. Whether it's unhackable type of communication systems, that's probably much further out, but really being able to get at the heart of security, even though it won't be certainly as fast as we need today, but it might be able to provide ultimate security.

More near term, when we think about quantum computers and how they're being fabricated now where we're at with maybe a hundred qbits, 400 or so has been shown out there, there's a point where we need to control these same dilution refrigerators, which are near milikelvin temperatures, which are really just above absolute zero. Very precise control is needed, and you think about being able to scale those out. You can't just make a dilution refrigerator that big. You're going to need to connect different modularities or different wafers with those superconductors. That really does form a quantum network there. I think that's going to be an early stage implementation of quantum networking, be able to connect quantum computers together to form a larger quantum computer and get to what we really want to be at, which would be a cryptographically relevant quantum computer.

Then last, ties in nicely with quantum computers. In the Air Force, we're certainly not building quantum computers. It makes no sense at all for us to actually go out and build the hardware. We're building components for networks which are very closely aligned. I'll talk a little bit about that I think later on. But really with quantum computers, we're looking at algorithms and problem spaces that quantum computers could ultimately be good at solving. We've made an early investment being able to access systems that are out there. Right now we're partnered with a couple different vendors including IBM and INQ, having cloud-based access.

That's allowed us to really get our hands dirty, if you will, with looking at what quantum computers could be used for. Certainly, some of the early applications that we see out there would be quantum simulation, quantum chemistry type applications, how to develop better materials, optimization problems you can think of certainly in the Air Force and then in the DAF supply chain and logistics delivery. Huge problem for us. How can we optimize over that? Finally, where we hear another great term, kind of a lot of hype right now is machine learning, AI. How can quantum enhance that and maybe improve those technologies? Really in those four bins is where the air force is focusing their efforts and very closely aligned would be the foundational research that goes along with that for better devices, things like better lasers, better electronics, continuing to have that cycle as we look to push out applications. Of course I think we'll have some time to get into this, but workforce development is key to us generating that workforce that we really, really need to push these technologies out.

Heather Penney:

I'm really focused on what the war fighter needs today. When we look at quantum capabilities that could be near term relevant within 5 to 10 years of actually being integrated onto our current weapon systems and future weapon systems, it really comes down to timing. Clocks that are millions of times better than today's current atomic clocks, like what you get off the GPS. Imagine what that could do for things like communication. Imagine what that could do for things like electronic warfare and electronic attack. That is probably the nearest term capability that quantum could deliver to the war fighter. The next one, inertial units and navigation. Michael's office recently did a magnetometry navigation demonstration, and that was phenomenal in terms of how they were able to integrate artificial intelligence to null out the magnetic signature of the aircraft to allow the magnetometer to be able to sense the earth's magnetic field so that it knew where it was. Now it wasn't precision, but it was good enough for government work.

That's an example of sensors that are near term to the war fighter or inertial navigation units using atoms themselves as accelerometers as like miniature gyroscopes. Now, that's not a perfect analogy when you get into the science, but again, it's good enough for us to understand the potential of using and exploiting our ability to control and measure atoms for the war fighter use. When you begin to marry those things up, you begin to see how this has a potential to solve a really wicked problem. When we look at the Pacific and what peer conflict, excuse me, would cause us.

To do that, again, we need to invest in the fabrication, invest in the production, and invest in a lot of the classical technologies. Classical technologies are those things that we deal with every day. Right? Transitions, lasers, vacuum cells. How do we take the packaging that we wrap up, this exquisite capability called quantum into something that we can shove into any old aircraft and get to do the things that we need it to do. The good news is that those classical technologies, by investing in a capability that we need as war fighters yesterday, has the ability to level up everyone's capabilities because there's a foundational set of classical capabilities that every single element from compute to timing, to sensing, to communication and networking that they all use. By pursuing a single capability, whether or not that's timing or inertial or sensing has the ability to accelerate the rest of the quantum field.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Yeah, very good. Let me backtrack just a little bit. I said in the intro that it seems quantum is always 10 years out and you've laid out some very important capabilities that may be derived, but as a baseline, and I ask Chester Kennedy this, and then Dr. Hayduk, maybe you can address this, but what technologies have the greatest potential to be operationalized in the near term? What's first with respect to quantum?

Chester Kennedy:

So we've talked about clocks. I think that is the nearest term, is seeing a million times accuracy and other important attributes about timing, a million times improvement over what we have today that we count as our standard. Heather's already alluded, well, what does that mean for us? Well, if I can take my CEP, if I can take my probability of where I'm going to hit my target from, let's say a meter down to a millimeter, does that matter? Does it matter when you think about hypersonics and you think about wanting to know where you are when you're moving at multiple times the speed of sound? That's real. Doesn't require a bunch of further scientific investigation. That's here today. The other one that we recently demonstrated a lot of success with is something called quantum RF. That's taking these atoms that are trapped inside these ultra-high vacuum cells, and instead of relying on a dilution refrigerator to cool them down, we cool them down with lasers.

I get it until I started trying to learn something about quantum, everything I had ever used a laser for in my past involved heating something up, not cooling it down, but when you understand what's happening there, these lasers actually cool these things down to less than a millikelvin above absolute zero, and then they become into a different state and we can do some other things with them. We can actually control the frequency at which those atoms become resonant, not by the length of the antenna, but by changing the wavelength of the laser that we stimulate them with. That's a couple of examples of some things that I think are real near term.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Very good. Doctor?

Dr. Michael Hayduk:

Yeah, I think we've already hit upon a lot of the things that I was going to bring forward, but just to maybe amplify a little bit on the RIMPAC experiments. So this occurred in 2022. Planning actually started four years before that. And the lab commanders had put this together as really a challenge to our technologists, our scientists and engineers who are working timing and sensing to take technology from the lab on these very large optical tables with lots of lasers components, vacuum chambers, all the things that make up quantum sensing and clocks, and how we could get those out into the field and do an actual test aboard a ship. Brought together the [inaudible 00:21:04] partners and really a very nice success in terms of some of the sensors that were tested, some of the clocks that were tested that the Air Force brought from our space vehicles directorate, along with a new type of cold atom accelerometer. The Navy brought some of their technologies as well, including INS type systems.

Then our partners brought some clocks and we were able to compare those, put them together in an architecture and really just a first look aboard a ship, how these technologies could actually work and give us things like not only GPS type capabilities, but ISR capabilities, electric field sensors as well, which we haven't really hit upon too much, but that was really neat. We learned a lot. We were kind of surprised with how good some of the results were. Now we're going to go back, retweak, and again, continue that research and development cycle to ultimately be able to push the technologies out because we see things like we heard the clocks and the sensors as being our near term application somewhere between now and say five years from now.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Yeah. Let me ask Dr. Crowder, setting this baseline, okay, what are the long term use cases? What can we expect to see out there on a longer time horizon?

Dr. Tanner J. Crowder:

I think as we look towards the long-term time horizon of 15, 20 years out, hopefully the use cases that come around them aren't known yet and that we still have the most exciting prospects in our future to be discovered that a lot of R&D is going to be needed to develop. I think that to realize these long-term prospects, to be able to develop a quantum computer and go past Shore's algorithm for something that might be used for say, pharmaceutical development or drug discovery, we're going to need a lot more people. Mike mentioned this earlier, that we need a workforce, we need a private workforce, and we also need a DOD centric workforce.

It's extremely hard to recruit people into the DOD, not only for clearance reasons and nationality reasons, but people just don't know what the opportunities are out there. As someone who spent 15 years at the Naval Research Lab doing scientific R&D, these places can be great. We need to be able to leverage our service labs. We need to continue the great work they're doing. We need to marry those people with end users, whether it's end users within the DOD or external to the DOD in industry to really push forward these designs.

The people that are doing the quantum information science R&D are not experts in mission level sensing or mission level computation. They don't know necessarily what it takes to take something that's sprawled out on a four by eight optics breadboard and condense it into something that's rack mountable that can maybe go on a ship or on a plane. We really need to make sure that we are properly getting these people to talk to one another and developing a virtuous cycle of research. The DOD has been doing this for a long time, and I think we need to keep up that good work.

Then just as a framing. It was first proposed in 1985 that we use squeezed light to augment Ligo, the interferometer that can detect gravitational waves. We first used squeeze light in 2018 to do that. The DARPA chip scale atomic clock program started in 2001. 10 years and a hundred million dollars later, we actually had a commercializable atomic clock or chip scale atomic clock. To take things from lab to actually bringing them to fruition takes a lot of time, a lot of money, a lot of patience and careful handoffs between R&D program managers and industry. I think the best thing that we can do for our long-term prospects is identify a few key technologies that would be useful to the DOD and really figure out what it's going to take to actually make the mission relevant and have a dedicated and focused effort.

Heather Penney:

I think what Dr. Crowder said is worth repeating. I'm really just going to repackage his words, right? As a war fighter, we need to do the requirements. We need to understand what our capability gaps are, how the technology of quantum can fill and meet those capability gaps, and then create requirements to challenge these companies to design to and challenge them to integrate into. It's one thing to demonstrate laid out on that laboratory table the ability to do timing or the ability to do sensing, but to give them a real operational problem. Because let's face it, the Air Force operates in pretty extreme environments and will become even more so in a peer and highly contested conflict. We need to give them that challenge to design to and to integrate into. That's really, I think, what's important is ensuring that we develop the requirements, the form, fit, and function, and ensure that we marry an actual war fighter user with the R&D and the technologists as they begin to build this.

This is how we built the Sidewinder. Now, the Air Force didn't build it, the Navy did, but that rapid iterative process of design, build, fabricate, test was crucial. That test was not in perfect environments. It was with every day Joe Fighter pilots going out to China Lake. It was not pristine environments that would result in pristine outcomes, and that's what will be really important for us as we begin to do the hard and heavy lift of bringing quantum to the war fighter, but I think it's absolutely essential. Dr. Crowder, thank you for those words.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Very good. Hey, well, I had like to go back to my opening comments and talk about some of our competitors out there, and China has invested a lot in this technology, and I'm curious the entire panel, your view of where that competition stands and how you see the consequences of falling behind in that technology competition. Maybe I'll start with Heather and we'll come down this way.

Heather Penney:

Well, I think we need to understand that China is committed to obtaining and continuing to maintain a quantum advantage. When I say quantum advantage, I don't mean it in the sciencey academic terms of being able to solve an algorithm that a classical computer could not, no, I mean it from a strategic and national defense advantage. This is a race and one where we must be able to continue to maintain a lead. China through their demonstrations has proven that they have the focus, they have the financial commitment, and the industrial commitment to achieve not just the science part of the quantum, but all of the other pieces of actually fielding it. The Micius satellite is one of the standard examples where they've beamed up through lasers encoded messages, and eventually they worked up to a VTC across continents. It was actually a pretty big deal.

In the United States, the NSA says, "Hey, we don't do that kind of technology because there are actually some vulnerabilities within what they demonstrated." But as I said before, every time you begin to master the difficult engineering problem of taking quantum out of the laboratory and putting it in the real world, you lift up your ability to master any of those fields of quantum, and that's what they're doing. They're demonstrating the ability to get that engineering and the operational piece in the real world. While some of what they do is really kind of peacocking, the other piece is we need to be really watching closely. If you don't understand the science, you can not understand what's real and what's not.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Very good. Chester?

Chester Kennedy:

Wow, I think that's a great explanation, Heather. It's easy for us to get in the mindset that in the US that we're going to have venture capitalists and we're going to have all these other sources of money that get poured into doing fundamental research. In a lot of instances that's true, but what we've done is we've kind of created a national economy of venture capitalists that are expecting a return in three years to maybe seven years if you stretch it out. From the conversations that you've heard here already today, this requires long-term persistent investment to really see this technology come to fruition. I think that's an area that we're vulnerable. The Chinese government doesn't have the same limitations and the same dependency on venture capital funds to move their R&D efforts forward.

Dr. Tanner J. Crowder:

I think that all we can do is control how fast we run. We can run fast, we can pour gasoline on these fires and really develop the R&D chain. Quantum technologies have the ability to revolutionize many economic sectors from finance to pharmaceuticals to materials discovery in a way that, like Charles said, it's going to be quantum in the kitchen and we need to continue to push forward and develop them. We need to be cognizant of the dual use nature of some of these technologies. The same gravimeters that might be able to track groundwater recharge are going to be the same gravimeters that we're going to be using for P&T. And so we need to make sure that we are leading in these critical areas. We are developing a domestic R&D and a trusted international R&D pipeline.

We need to be developing the necessary infrastructure to be able to implement these technologies as they come out. We need to just be able to continue to push forward, and we need to continue to mitigate the risks of quantum computers through the fast implementation of post quantum cryptography and quantum resistant cryptography. I'd like to highlight the national security memorandum on quantum computation saying that we need to really get our most precious assets to post quantum cryptography by 2035, and a lot of that's within the DOD. I think we need to impress upon our leadership that is of huge importance. I'll just close by mentioning the recent OMB OSDP R&D priorities memo, which redouble down our efforts to invest in the critical emerging technologies that are going to drive national security issues such as quantum technologies.

Dr. Michael Hayduk:

Yeah, so I'll just maybe foot stamp a couple of the points that were said already. First off, China, it's something we track really on a daily basis in the Air Force in terms of what's being developed by China and what's fact versus fiction versus hype versus reality. But as Tanner said, we can control what we can control, and that's where we really need to think long-term here. Right? It's not a short-term game. I heard this analogy before I got a couple analogies. One is it's not even a marathon because it's longer than a marathon. It's not 26.2 miles and you're done. It's going to keep going. You think of our semiconductor industry and processing technologies and where we're at with the Chips and Science Act. Looking long-term that this is going to keep going, but it's really a race we can't lose, as Tanner said, because of all the other implications for national security and economic competitiveness within the US.

We need to be first. We need that long-term view. The US has been investing a long time in this. The DOD has been investing in a long time in this. But another analogy I have in our information directorate overview, we used to have a slide that said it takes 20 years to be an overnight success. You think about that for a little bit. This is where we're at. We have to be in it for the long haul with quantum because it's hard, it's not easy, and other countries are doing it, and we certainly can't be last and we need to be first.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Yeah.

Heather Penney:

I'd like to build a little bit on what Dr. Crowder and Hayduk said regarding the requirement for the DOD to be committed to the hard work of fielding quantum. To tie in to what Chester has said as well, we can not rely on venture capital to bring it to us. Their financial incentives and the demands and their timelines don't match what the science requires what's going to be required in terms of, no kidding, the money necessary to build the production and facilitation of the hardware necessary for quantum. Also, if the capabilities, the sensors, the clocks, et cetera, are very unique to DOD needs, there's not the large commercial return or profit margins that these venture capitalists are going to need. Oh, by the way, here's something that we also need to consider. The small business incentive programs, whether or not that's Sibers or Afworks or Prime or et cetera, they are not well suited for the demands of these small quantum startups.

We need to think differently about what's necessary in terms of focusing where our programs are, where our funding is, to do the long-term work that Dr. Crowder and Dr. Hayduk talked about. Because we need to start understanding what are the capabilities that we need to focus on to ensure that instead of spreading out thinly a lot of dollars that don't really move the R&D forward and aren't really enough to sustain the quantum ecosystem out there, We need to focus it so we can actually begin to move the R&D forward with a few small efforts.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Very good. Well, let me seg another direction here I think is important. We've got about five minutes left and there's this such a fantastic topic. It is true that the advance of quantum is going to rely heavily on traditional technologies. I'd like to ask Dr. Crowder and Chester in particular et al, where would we be prioritizing investments in those traditional technologies to make sure that the way is clear for quantum overall? I

Dr. Tanner J. Crowder:

Briefly, I think one of the best things we can do is invest in the cross-cutting technologies that are going to be used not only in classical systems like integrated photonics, but also quantum systems for quantum networking and quantum computing that are going to enable things like transduction and entanglement distribution. I think that's how you buy down your risk is by investing in cross-cutting technologies, developing the infrastructure, figuring out where the DOD in particular can pour gas onto the fire and buy down some of the risks that might not be profitable for industry, but it might be a breakeven for the DOD as Heather mentioned. I think that's one thing that we can do. We really need manufacturing infrastructure and this can be seen with the Chips and Science Act and the DOD commons. I think that as we look towards building these classical components up, I think we need to be looking to build those crosscutting infrastructure that's going to be used for quantum computing, sensing communications, and also those classical technologies like integrated photonics.

Chester Kennedy:

I think you hit it pretty much right on the head there. The laser and photonics piece of that, getting to integrated photonics is really close and it has a lot of other applicability. And that's one that's really going to change the space for the modality that we work in with inflection called quanta where it's cold neutral atoms and you heard me mention using the lasers to be able to do the cooling. As we get just a few more steps forward in the roadmap on integrated photonics, being able to implement that cooling function, not with a 3 19 inch rack, 3U 19 inch rack of the lasers behind this little fiber that comes out and works on this little glass cell, but rather being able to integrate that glass cell with the photonics.

That's something that is definitely on the path to achievibility with just a little bit of continued acceleration from the programs that Dr. Crowder mentioned.

The other one that we don't want to lose sight of, I think is the ability to produce these ultra high vacuum cells themselves. I've told folks before that when I joined Inflection, if our board hadn't had a little bit of a sense of patriotism to them, they would've put me on an airplane and told me to go to China and not come back until I had established a manufacturing source for these vacuum cells because it is something that doesn't exist in the US. It's the kind of thing that China would invest in and cover the cost of standing up the infrastructure to be able to capture the IP and to build a long-term dependency.

Fortunately, they've given us some latitude there and building out that manufacturing infrastructure is something that I'm passionate about and that I believe is critically important to our continued leadership role in quantum here in the US.

Heather Penney:

I think we also cannot forget how do we integrate the quantum capability onto our normal weapon systems. How do you receive whatever that quantum thing is, and that's another important piece of the classical capabilities.

Maj. Gen. Larry Stutzriem, USAF (Ret.):

Thank you, Heather. Well, I tell you, this has gone very fast and we're out of time and we're going to invite you back in 10 years to grade you on your talk.