Science- ANSTO – Nikolas Paneras transcript  
(Duration 40 minutes 17 seconds)

Presenters:   
Nikolas Paneras  
Chris Bormann

(soft music)

Chris: Welcome to this resource for supporting HSC science students. In this series of interviews, we investigate the role, application, and operation of particle accelerators in contemporary science research. In this interview, you'll be hearing from Nikolas Paneras as he discusses the range of particle accelerators used to support research along with their operation. He will also outline how they are tuned to suit research needs, and highlight the importance of maintaining them to ensure optimum operating characteristics. I hope that you and your students enjoy this resource and that it assists in adding context and depth to the scientific concepts in your Stage 6 Science courses.

Chris: Welcome today, we are fortunate to have with us Nikolas, who has worked in the accelerator science industry for 15 years and developed extensive technical experience in the operation of particle accelerators, working to produce a range of radiopharmaceuticals using cyclotrons and also in the operation and maintenance of atomic mass spectroscopy machines. Nikolas is currently responsible for the maintenance of the electrostatic accelerators as part of the AMS setup at the ANSTO's Lucas Heights facility. If you need someone who can fix things and operate your million plus dollar accelerator, then Nikolas might just be your person.

Welcome, Nikolas.

Nikolas -: Thank you.

Chris: Now can you please describe your area of research or work, its purpose and how it might influence our lives.

Nikolas:Okay, well the particle accelerators that ANSTO has, have a few different purposes. So as you said earlier, I started work on machine called a cyclotron. It's a 30 million electron volt cyclotron, which means that it accelerates protons up to 30 million electron volts, slams them into a target material, and in doing so, changes them from a stable element into a different element that is radioactive. And with that radioactive isotope, you can label it to a particular chemical and inject it intoa person and that chemical will go to a particular place, and you can image that person's biology in real time. Also, some of the isotopes are used for mild therapy. So you can target a particular organ and give it a mild dose to kill off a cancer or treat some other illness. The other accelerators that we've got, the electrostatic accelerators, we have four of those, a one million volt, two million volt, six million volt and 10 million volt machine. They're use to accelerate particles of a sample that you've collected and accelerate it through the machine, separate out the different masses and then you can analyse the ratio of those masses to see how old it is? What it's made of? And there's also another process where you accelerate a particular particle you want, can be a proton, it can be carbon, ion, vanadium, whatever you want, and you slam it into another material, you change its material properties, and you can analyse how that works. You can also have a sample at your target station of a priceless piece of work to see what materials Van Gogh might have used. Did he use some paint that had chromium in it? Or did some Incan mug have gold in it or what have you? That's a non-destructive process.

Chris: Now, you mentioned that there was a range of energies that are used from a million volts or electron volts, corresponding, through to 10 million or more. Is it just bigger is better? Or what is the, what's the difference in the capability that you get from going to higher energies?

Nikolas: Bigger is not always better, you just need to select the most appropriate energy. But some things need a great deal of energy to be able to analyse. So we do still have the 10 million volt machine. It's our oldest one. It is a very reliable machine. And it does most of the environmental studies, which you'll be able to hear about later, with the other scientists.

Chris: What's the difference in the capability that you get from going to higher energies?

Nikolas -Okay, in the cyclotrons - we'll start with those - there is a 'what's called a cross-section that a particular target material will accept into its nucleus a proton if you're accelerating that, at a particular energy and you can transmutate your target at that energy. So you need to choose the energy that's got the biggest area that will capture that particle and then undergo that nuclear reaction. The electrostatic accelerators, you want to tune the energies because that's basically the speed, you're giving the particles that you will end up bending and turning around corners to separate the masses and to analyse this the materials that they're made of. So, the electrostatic accelerator is a very widely tuneable for energies because you want to see the particles of interest to the right detector, the right places, Faraday cups, all these mechanisms that collect information.

Chris: Is there a way that you would be able to explain what a what a cross section is and how it relates to science.

Nikolas: Sure, sure thing. If you take the analogy of the stadium, so the spectators in the seats of the stadium are the electrons. So there's small people in seats, and they're very much at the end of the stadium. And the nucleus is the ball in the middle of the field. That's the real scale of how things are. So most of that atom is completely empty space. So the cross section that we talked about is the apparent size, that if you were to fire something into that stadium, the apparent size of the ball changes with the energy of the particle that comes in. It's a strange analogy to use. But if he's wanted to say that, if I shot the proton into the stadium at 18 million electron volts, that ball in the middle, which is the the oxygen nucleus will appear to be much bigger than if I shot it at five or 25. So there is a sweet spot, it's like a curve that you get a nice peak. And there are a few peaks some are at ridiculous energies, where it's basically, firing 10,000 cannonballs into the stadium, you're going to hit something, but we can't achieve those. So you've got to choose the most achievable economic peak. And that's where you get your most efficiencies. So the cross section is like just building a bigger target board, you choose the point of energy where your target appears to be the biggest.

Chris: And in terms of your laboratory, you've talked about some of the machines and things that are there, they're quite the range. And how else might be different from a school science laboratory?

Nikolas :Yes, there are some elements that are the same. We still do have a chemistry group that has a lot of the bunsen burners and the glassware. But our facility is very large, the accelerators are massive and they have lots of different components on them that requires a lot of different disciplines of interest. So we have an electronics lab that has all the oscilloscopes and the soldering irons and power supplies, all those sorts of things that you may have used. We have a mechanical labs where they make the beamline tubes they serve as the vacuum pumps. They machine out with big ingots of aluminium, stainless steel, different components that we try out make ion sources. Accelerators are housed in very large buildings which we have, for one of a better word, like big tin shed and they're cold. We have air conditioning but doesn't work. (laughs) There are lots of bits and pieces. So you go around most of your days made up of tinkering with this little thing, can we get it to work better? Can we fix it? Can we improve it in some way? If you have an idea, you take it back to your laboratory, you put it together and you try it out, and it may or may not work. A lot of things don't work any better than what's out there, but a lot of things do and then you move on to something completely different. You work with the researchers and the scientists to perhaps get the ion source better. So you think of a different gas manifold that you can put on, you can slap on some microcontroller project that you've thought out just to try out a little, an idea, if that works, you put into a PLC controller and make it industrial strength to withstand the nuclear winter. And there's all sorts of things that you can do. So it's a lot of fun. Everything we work with costs a great deal of money. And you get to play with it, really big toys, but you've got to be responsible, do you've got to be careful because if you break lots of stuff, you may not stay employed for a long time. So you've got to have fun with what you do. And there's a lot of fun to be had in science, it's great. Physics is fun with a PH.

Chris: In terms of the particles that you are accelerating, but how do they make it from that source to the right parts of the detector so that you know what it is that you're counting?

Nikolas: Everything that exists naturally in the air, in nature. So you spotted that they all start moving, and you select the right mass range with this first magnet. So a charged particle will turn in a magnetic field, different masses will have a different radius of curvature. So you select the magnetic field that steers the right range through to the next part of the beamline. And then they drift along and they enter into the start of the acceleration tube, which is a very long tube that has many different little plates in it, and each plate between it has about 30,000 volts of acceleration potential. So they move along, and those have a gradient of voltage all the way up to the terminal which is in the middle of the tank. So they get a little bit of speed a bit more, a bit more bit more, a bit more bit, a bit more, until they can get up to the terminal which is at whatever voltage you select, let's say six million volts. And inside that terminal, those extra electrons that we put on the outside that we added at the ion source take, we'll strip some of them off so it changes the polarity. So instead of being net negative, they will have some other potential, so positive and they'll be repulsed away so you get trapped in and then you repulse out so you give it a good kick through the accelerator. Once you exit the accelerator, you then do a big almost usually it's quite a not right hand turn. Again, you start to separate out the finer tuning, where the masses you want will turn around that corner. The other masses just go straight on through. Remember you're only counting atoms at this point. It's not a big mass where you're going to burn a hole in the beam line. It's only one or two spattering per second, and they will turn around a corner. And at that point, you can select off the main beam line into other measuring points. The masses that you don't want but are still a point of interest. And the mass you do want goes all the way down to the detector, fine tuning through different focusing elements each way. So in the carbon you're looking at 11, 12, 13, 14 and at those points you can see they're off axis cups that select those particular masses and you can check the ratio you want. Other chemicals I look at are beryllium, and I look at chlorine and aluminium, the cosmogenic made up for the cosmic rays. They tune those masses down the beamline and they just count the atoms over a particular point and they can tell some stuff about the environment through that.

Chris: Right so in the process there's an accelerated chain.

Nikolas: Oh, yes.

Chris: And essentially, you don't want to accelerate everything up to its maximum speed to begin with, because you are looking to discard some of the sample. And that's part of the rationale there.

Nikolas: Yes, absolutely. So you are selecting particular a range of interest on your elements. So you can change it through your experiment, as you tune the machine for those particular methods, but at the start you tune range, so you get to discard the majority of the stuff that is not of interest. And then after the acceleration, you then have the energy in those particles to do the fine-tuning with big magnets, electrostatic steerers. You can make the beam go out, make come in, make it focus, all these sorts of things. A lot of electrostatic optics, magnetic optics that go on to make the the right stuff go into the detector that you want to measure. There are also some fancy things called bounces. So you tune your machine up to the centre mass. And there are these plates that just kick high voltages between the magnets that make the beam tick. So you got your centre mass, and you can tick to the left tick to the right. So you say if you want 13, the centre mass, you can check out 12 by kicking it this way, you can check out 14 by kicking it that way. There's lots of little bells and whistles that go on extra features that make the science quite interesting. And it needs, it's a great area to be in.

Chris: Excellent! In terms of the, you're talking about the particle energies, and how much they bend depends on on how fast they're going. When we say that we've got like a constant accelerating potential that you're putting them through. These particles are slightly different. Do they do they all end up going the same speed or is it the energy that is the same only?

Nikolas: Term to have but that the particles have a particular energy. So it depends on how many electrons they're carrying. And the the accelerating potential you bringing it up to. So if it was only carrying one electron, and you accelerate up to six million volts, it's have six million electron volts. But most things don't don't only carry one electron around with them. So if they had four, you'd have six times four, 24 million electron volts. So that energy that they going in with comes out of the machine and you're usually concentrating on one species, so you can keep that as a constant, but their masses will be different. So let's take a sweeping corner on the road as an analogy. You've got a sports car like a MGB tearing along at 100 kilometres an hour load off the road, and you just take the corner oh, ouch. Around the corner, it goes and then you have a big garbage truck coming along at 100 kilometres an hour, its mass is very different. It can't take that corner, it's going to go straight and not be able to turn. So the mass of that car, the small one, allowed it to turn the corner nicely. The truck only made it halfway around the corner and went off the edge because it was much heavier. So the magnetic field that, that particle goes through determines the radius of curvature for particular masses. And that's how you separate out your different isotopes because they have different masses.

Chris: Well, I could see it I in terms of the students designing an experiment at school, we will look at, you've got your independent dependent control variables, and it sounds like that selecting for the charge and keeping the energy also the same than it is just that isotope mass.

Nikolas: That's right. And part of the whole importance of the keeping the energy potential in the accelerated potential completely flat is very important. Because if that fluctuates, flickers goes up and down, that resulting beam coming out at the end and going into your detector will be swinging left and right. So you might capture some not capture some. So your measurement might have holes in it, gaps in it because the energies are fluctuating. So we try and keep the energies as flat as possible.

Chris: And that's what they're counting on for you.

Nikolas: That's right, yeah, that's our responsibility. And it's not easy. It's not easy keeping 10 million volts stable, or 6 million volts. That's why these accelerators are in massive tanks of a gas called sulphur hexafluoride, which is an excellent insulator, say we're trying not to lose charge out of the terminal. Because if it just set in air, just be sparking to the ground to the roof to people. So you try and keep jammed in an insulator, so it doesn't fluctuate, lose charge and go up and down in it's potential.

Chris: When you're working with a group, I take it as there is other people who are performing a similar role to you. Is there any sort of friendly competition in terms of that ability to maintain the machine at those great operating characteristics?

Nikolas: Absolutely, absolutely. Especially in the cyclotron field, because a cyclotrons are much smaller machine, it's usually got one or maybe two people that take care of it. So you have a very personal pride, you might say, against the machine. What is the best vacuum you can get in your machine because that's sort of cleanliness of the machine and that's how healthy it is. Vacuum is very important. What energies can you get up to, what yields how much isotope have you made in the day and in the electrostatic accelerator field is just how stable can you get the machine. These sorts of things, it's very much a pride and when we go to our user groups or our forums, it's Yes, it's bragging points you could say. So yes, there's a lot of pride that goes into getting these very difficult machines to behave and break the boundaries each time.

Chris: And are you able to describe, sort of what a typical day of work might look like?

Nikolas: A standard day basically starts with having a small meeting with your team, making sure that everything's working fine. If things aren't, if there's something's broken down, we all act on that and get that fixed. Next, we'd probably go into some planned maintenance to make sure things don't break down. We then get to do our personal projects, some development work, which is always exciting because it's not always fun fixing things that are broken, but it's the job. And the project work ends up going on the machine and if it works well you get to share that information with your colleagues and brag that you've done something better. So it's nice, it's nice to see your work making this already complicated machine something better. But it's as a group, we all do it together. But every day is different. There's always something going, it's never dull. (laughs)

Chris: What was the young Nikolas like at school, was in terms of science or, can you describe that for us?

Nikolas: Science was always my passion from from a young child, I would pull apart a clock radios and everything and most of the time not put them back together. But at school, I always followed the sciences. I did all the sciences I could in computer science, things like that. But I did find physics to be where things fell into place. I found that schooling basically arms you with a analytical mind, a questioning mind. It's not only the equations and what this person did some old Scottish guy from the 1800s, Maxwell and Faraday and this and the other you, those things are just wired into your head, you may forget their names and exactly what they did. But it's the way you go about thinking about something, that knowledge is in the back of your head. No, thinking if I apply this magnetic field, I don't have to do the Lorenz equation on a piece of paper. I think, oh, it's going to turn about this far. It's all in there. So if you do this, if you study, you're basically wiring your brain in a particular way to think a particular way. And it's a toolkit that you carry around with you. And if you've got the passion in a particular field, you follow it, but be prepared that the future might not be the exact thing that you want. And don't be disappointed because I've been doing science since I left University, but it's been in so many different fields. I used to be the person on the manipulators in the glove box, pouring the chemicals when I first started and stir, and then I moved to the cyclotron group and then I was turning dials and making a beam go somewhere and making lots of radiation. And then I move to this other group here, and I get to work on million, million dollar chains. And each bit of equipment I touch is worth thousands and thousands of dollars. So your responsibilities and your interests change. It's very malleable, it's like a bit of play dough, it's sort of the same thing, but it gets changed in shape. So study is just putting the right tools in your toolkit. And you go through life with that. I as a student got a little bit disheartened because I wasn't getting 100% all the time, and I was chasing this 100% thing. You don't always get it. You might come sick, you don't cry into your sandwich at lunch. You go into study with a clear mind, and that you've done your best because you have to do your best. To get somewhere you need effort, you don't just ride the wave, you need to put effort in. But you don't you don't exclude the rest of your life for study, you make study part of your life. And you make it a nice balanced environment. And that way, you'll enjoy it and you'll get the most out of it.

Chris: Can you describe the importance that questioning has in science and in your work life? Where the questions leading.

Nikolas: Questions are key, absolutely. If you have a technical and engineering or scientific mind, you want to know how things work, you don't just look at something and you go, I'm sitting in front of this computer. There's a screen there's a keyboard. I just put information in it shows me some things. No, what's that humming sound? That's a fan. There's a hard disk drive in it, LEDs in the screen. You want to know how things work, because when you have an understanding of how this thing works, you know how it's going to behave, how it's going to react. And having that intimate knowledge with that technology you're using, or looking into nature, how does that plant produce flowers? Why does it produce flowers? You get to know the nature, you get closer to how the universe works. And you can think in that manner, and you can apply yourself to your passion and the science you've got in front of you. So just accepting things at face value may be convenient. But if you have a scientific mind, you want to know how that works, how that ticks. And that was always my case.

Chris: You've got experience with using a range of accelerators and we have talked about linear or electrostatic accelerators and cyclotrons. What sort of similarities and differences are there in their operation.

Nikolas: Okay, the two main differences in those machines, so just briefly is one is a DC machine. So one has a static potential and the other one uses an alternating potential, alternating current at radio frequency levels. So the electrostatic accelerated like the name says electrostatic it's a static potential and the particles that come into it see that very steady potential they get accelerated, stripped and then repelled out and you get that lovely constant flow. Whereas the cyclotron because the acceleration path is around and around and around and around. You need to flip the potential because it goes over something called Ds. In the original cyclotrons the circular section was cut in half, so you had one D on one side and another D on the other side. And the acceleration gap was between those two Ds down the middle. So you had to ionise your hydrogen molecule to make a proton, and you need to add an extra electron. So it's carrying two electrons instead of one. And you'd apply a potential across this gap and give it a bit of movement. It's in a massive magnetic field, so spin around, and then you accelerate it again, and spin it around again and again again, and because of the Lorentz force, the more velocity had, the more energy it got. The radius of curvature got greater and greater and greater, and it spiralled outwards until it got to the outside, where it'd go through a strip of foil. It's a very thin carbon foil, you'd steer both the electrons and it repel it in the other direction. So instead of going around this way it'd get kicked out. That's where your beam line knots was and you remove it. The electrostatic accelerator is a nice straight path. You give it as much energy as you want to. And then outside of the accelerator, you do all the fancy separation and analysis.

Chris: How do you tune the energy of the the particles the protons in the end of a cyclotron?

So there are a few different things that take up the tuning of the cyclotron. One, you need to balance how much of a beam of protons you're putting into the machine so it's the ion source. So the ion source takes normal hydrogen gas ionises it and makes a little plasma bottle. So you have a large magnetic field and you have a little cylinder and the particles are spinning around and they ionise each other. And you apply a small potential to draw those ions out, and then they enter into the larger field. So if you're flooding the area with too much beam beam is not going to be nice and pencil like it's going to be very broad flat, and you won't be able to separate and things will have a range of energies. If you'd put in too little in, you're not going to make anything at the end you're not going to bombard the target much. So you need to tune the ion beam. And then you change the magnetic field to change how tight or how loose the spiral is. And you have to align that to exactly where the strip of foil is. And then you have the stripper foil angle, which sort of changes the trajectory of the outward beam. If you've got it at an acute angle go too much this way, if you got too oblique, it will go too much that way. So there's three major elements. Whereas with the electrostatic accelerator, getting the potential inside the accelerator is, as you say, the easy part. All the tuning goes on outside the accelerator. You tune your ion source to get the right range of masses and you've got to steer those into the accelerator, right down the middle of the tube. Once it exits the accelerator, you've got to turn it around the analysing magnets and steer it down towards your detector and get the beam very much down the centre. Remember, these machines are massive, so it's the turns of the angles. So if you make one minor correction upstream, it's going to be some massive deflection downstream. So all these minor fluctuations that might be going on early on, you then give them 6 million volts of energy. You're going to be going all over the place, so that the tuning on the electrostatic accelerator is all on the outside and that is the difficult part. That's where the accelerate a science is.

Chris: When producing radioisotopes, how do you check for the the purity and the yield of the product?

Nikolas: Okay, so as you irradiate your target, you're basically throwing charged particles at a target material and wanting to change it from one atom to another that is radioactive. So we call it a current because it's a stream of charged particles going into a material. We measure that current, and we say per current, we should get so many transmutations into another material. So that is the initial target yield. So, per current, we should get so much radioactive stuff. And if it's off, we've had a bad run. It's too much, you've broken the laws of physics. (laughs) So, you should get so much radioactive material, beam current is the starting stuff, then we go and do the chemistry. So we extract the impurities we don't want out of that target material, and we take out just the isotope we want. So that's the next level of yield. So how much efficiency you've got at the extraction, did you leave a lot behind, was it wasted, did it get extracted. And then we react that with our reagents to make our targeted chemicals attached to that radioactive material, and you should get a radioisotope. And that process is not 100%. So we'll lose some in that as well. So that's another yield efficiency that you've got. If you add all those up together, you get your from target to radiopharmaceutical yield. But then you have to check that pharmaceutical, does it have some other isotope in it? Some transmutations don't only make one radioisotope, they make a small fraction of others that may be undesirable. One we used to do with the large cyclotron was thallium 201 used to get thallium 200 in there as a small percentage, but we also used to get 202 and both of those were undesirable one was too soft. And it's just another impurity in there taking up space. And the other one was a very hard gamma that could do a whole deal of damage. Instead of it just being a diagnostic tool, you ended up getting a radiotherapy. So we wanted to see that the right radioisotopes were being labelled with the right reagents and right traces to go to the right basis. So you put it in something called a gamma spectrum that looks at the photons coming off those radioisotopes, and they all have a certain footprint, a certain signature. And you get this funny spectra of all the energies and their intensities. And the software would say, okay, at this point, and this point, and this point, these are the peaks for this type of thallium, the 201 and they should be very large, was the 202 and the 202 should be very small. So that's the radioisotope purity you're looking at, but then there might be some other chemicals in there that aren't desirable. So you do a liquid chromatography analysis where you're forcing a liquid through a column that's tightly packed with a particular type of high surface area material. And different chemicals would progress up that column at different rates. And you could tell where they were spatially along the column with a little bit radiation detectors. So you could say, hang on, this shouldn't be here yet. So that means that the radioisotope has been labelled to something else. So it should follow a particular pattern or footprint in the chemistry in the purity of the isotope and you should get a certain yield from the start to the finish. And if they're outside of that, something's gone wrong. And that is a very tightly controlled environment. We have to get all our processes validated by the radiopharmaceutical regulator who does normal drugs at the chemist. So if you get your Panadol or your paracetamol, Ibuprofen, what have you. The therapeutics, good administration has to take your process off as robust, repeatable, and it delivers what it's supposed to. So all those rigours are in place. And there's a lot to do to get to a particular safe point. And we're very lucky here in Australia that we've got it, it makes our job hard. But it makes everybody at the other end safe. You're getting what you're going to be injected.

Chris: How much do the researchers rely on the quality of the product that you're able to produce at the cyclotrons.

Nikolas: So researchers like Maggie are coming up with new radio traces. So they're coming up with new chemicals, new molecules that want to target a specific area, nowhere else, because you don't want to flood someone with radiation because you'll do damage elsewhere. You want it to go to a very particular place to do a particular job. So those researchers want the most pure stuff that the cyclotron operator can make. So they want to know that the isotopes they're getting out of the cyclotron are dead on fluorine 18, carbon 11, whatever they are particular particular isotope that they want. They want to know that I've made it or the operators have made it correct. Otherwise, their results are going to be off the mark. And it's going to spoil their research study. And a lot of these studies, use models that have been going on for many months, if not years. So if you miss a beat, you can stuff a very long study in moments. And most of the isotopes that come out of the cyclotron are very short lived, their half-lives are minuscule. It's been a while since I made it but I think fluorine is an hour and 20 minutes and carbon 11 is only 20 minutes. So with carbon 11 they're basically tapping on the window of the control room, going, come on, come on, come on, because as soon as I finish making it, the stuff is decaying away. So it halves its activity in 20 minutes time. So that's why a lot of cyclotrons exist within a university campus that has a hospital attached to it. Or in special facilities like ANSTO, where the researchers or the end users are right next door because they have such short half-lives. So the purity of all the starting materials, including the radio step needs to be top-notch and the timing is very important.

Chris: So Nikolas, particle accelerators and their associated detectors have been described as giant microscopes. Can you elaborate on the role that increasing energies in these accelerators has on observing the world at the tiniest scale?

Nikolas: Okay, so in our facility, we have the two fields. The Mass Spectrometry, and we have the ion beam analysis and they both can be used as microscopes. So they're AMS field, you take your sample that you're studying, and you give it a high energy as you spin it or accelerated through these different particular elements, and then you see what it's made of, at the end. So, you're taking the smallest molecule in the energy and you're selecting the masses and you're saying, okay, it's made of this and this, and you can see at the atomic level and the molecular level, what it's made of. Another part we've got is the ion beam analysis, we take a particular particle can be whatever you like, you give it a certain amount of energy, and you slam it into a sample, this is the non-destructive part. And you can analyse the surface see what the material is on the surface, was it made with gold, was it made with silver? Does it have cadmium? Does it have other materials? So, you can bring in a precious artefact from a lost civilisation. And you can say, What did they make this paint with and they can see the pigments are made up of a particular element because you're firing a particle in, you can have a Rutherford backscatter, whether those come back out and that particular patterns and the particular angles of incidence give you a characteristic piece of information about what it's made of, energy you give it, the further you go into the sample, you can start to react with the sample. And when it decays back, you get some energies coming off, you can get X rays coming off, you can get the electron show, you can get gammas coming off if you go into the nucleus. And all those spectra of all those energies coming back at you in the different methods give you an in-depth view at the very, very, very, very small scale of what those things are made of. And by changing the energies, you can change how you interact with those materials. So you can see the very minute scale, we have something called a microprobe microbeam, which is a very, very, very small dot of these particles we accelerate, usually carbon or protons, and they scan over the surface. So it's like a scanning electron microscope, but not with electrons, with other nuclei and you slam it in there. And you get that information out. Absolutely, for such a small nation that we are, we punch very much above our weight. We are very strong in science.

Chris: Again, we are very, very grateful that you can share some of the exciting work that is going on at the moment in Australia with us and our students.

Nikolas: My pleasure. Well, I have to thank the likes of you guys, teachers who gave me that passion, so I really enjoyed the science because of the teachers I had. I think even though was inquiring as a child, they sort of brought that out. And you guys are underappreciated, and I really thank you for doing what you do. (gentle music)

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