Science-ANSTO- Dr Andrew Smith transcript

(Duration 32minutes 27 seconds)

Presenters:
Dr Andrew Smith
Chris Bormann

(gentle music)

Narrator: 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 Dr. Andrew Smith, as he discusses the role that accelerator science and Antarctic ice cores play in collecting evidence to support an understanding of Earth's climate in the past. 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 six science courses.

Chris Borman: Hi everyone. Today we have Andrew, Dr. Andrew Smith joining us. He is a principal research scientist at ANSTO with over 30 years of experience, working with particle accelerator systems. He specialises in accelerated mass spectrometry, AMS, and its use in revealing how earth's climate has changed over time.

His interests and expertise extend beyond the laboratory with Andrew leading several expeditions to Antarctica, to collect air, snow, ice core samples, as part of his research to improve our understanding of the past and the current status of Earth. You may also recognise him from ABC's Foreign Correspondent, and he starred in an episode earlier this year, titled "Atom Hunters", which documents one of his recent adventures to Antarctica. So thank you very much, Andrew, for joining us.

Dr Smith: Thank you, Chris.

Chris: Fabulous. And if you can, would you care to describe for students and teachers, some of your, your research and work?

Dr Smith: I've been here at ANSTO, which is the Australian Nuclear Science and Technology Organisation in Southern Sydney for 30 years now. And it was originally hard to get this machine set up as an accelerator mass spectrometer. And we'll talk a little bit more about that in a moment. Since our machines have come of age, as at were, and have started doing what they were always intended to do, my work has become less technical in nature, and I've been doing much more applied work. Now that applied work involves both my own research, which you've given a brief glimpse of, but it also involves, of course, doing work for other scientists and other students because we're a national facility, so people can submit samples to us for isotopic measurements through the ANSTO research portal.

(Image of exterior of Chemistry building of Centre for Accelerator Science at ANSTO as well as onscreen definition of acronyms AMS-accelerator mass spectrometry and IBA- ion beam analysis). So I've worked at, as you've explained, at ANSTO. We're in the Centre for Accelerator Science at ANSTO, and that's a view of our chemistry building. A lot of chemistry is involved, as well as physics in the kind of work that we do and we have four machines in what we call CAS. We have, they're all tandem particle accelerators and I think one of my colleagues, Nikolas Paneras has explained basically how these particle accelerators work. (Image: 4 photographs of the interior of the CAS indicating the physical size of the four accelerators).The largest machine has got a terminal voltage of 10 million volts. That's the Antares machine. So that's the machine that I have, up until recently, been doing most of my research on. The smallest machine, Vega, has a terminal voltage of a one million volt machine. And in between that, we have a two million volt machine, Star, and a 6 million volt machine, Vega. Now, as I said, these are tandem accelerators and that refers to the way that the charged particles are actually accelerated. Tandem accelerators are useful because they can produce beams of much higher energies, than the terminal voltage might suggest. But they're also particularly useful for accelerator mass spectrometry, because the ions start off negatively charged. The two main users of this facility, are the ion beam analysis people and the AMS people, the accelerator mass spectrometry people, and we both use the machines rather differently. The ion beam analysis people put their samples at the end of the beam line, and they bombard the samples with ions of known mass energy and charge and they look at the reactions that take place. And that way they can learn a lot about the chemical composition of their targets and how the chemicals are distributed on a very fine spatial scale. They can also modify the materials of their samples by ion implantation.
[Slide reads: What is Accelerator Mass Spectrometry?

* • AMS is an ultra-sensitive method for measuring isotopic ratios
* •AMS differs from other forms of mass spectrometry in that it accelerates ions to high kinetic energies before mass and energy analysis
* •AMS is based on atom counting so it is inherently sensitive
* •AMS is typically used for radioisotopes that have intermediate half-lives and/or very low abundance: often’cosmogenic’].

We don't actually care about the fact that the carbon-14 nucleus is radioactive at all. All we care about is it's got a mass of 14 and it's got an atomic number of six. And then, as I said, we use powerful electric and magnetic fields to separate ions of different mass, charge and energy as they pass through the machine from the ion source to the detector. So accelerator mass spectrometry differs from other forms of mass spectrometry in that we use these very high electric fields to accelerate the ions to very high velocities before we do the mass and the energy separation. And this means these machines are pretty big. So the Antares machine, I haven't measured it recently, but it's something like 70 meters from the ion source to the detector. It's a big machine and it occupies two large buildings. Our other machines are intermediate size, but they're still quite big, complicated machines. They're much bigger than a normal mass spectrometer, which will typically sit on a table top. But you can't do radiocarbon analysis with a mass spectrometer. The ultimate trick with AMS is that, because we have these very high energies, when we shoot the ions into the detector at the end of the beam line, we can look at the way they lose the energy we gave them in the accelerator and they give a characteristic signature that allows us to say, aha, “that must've been a radio carbon atom entering into the detector. And there's another one. And there's another one”. And so we can make a measurement, an accurate measurement very, very quickly with our machine. And at ANSTO, we're particularly good at making these isotopic ratio measurements on very, very tiny samples of carbon. Samples as small as just five micrograms or five millionths of a gram, which of course is just the merest hint of the speck of a suggestion of carbon. You can't see this, but we can actually detect and count the individual atoms within that. And we can make such a measurement within about 30 minutes or so. And this has opened up a whole range of opportunities for scientific study that just simply weren't there before.

(Image: cascade of events due to the collisions between cosmic rays and the nuclei of atmospheric gases, where some of the particles produced reach the Earth's surface and data showing half-life for some common cosmogenic radioisotopes such as Be-7, Be-10 and C-14). And in fact, most of these radioisotopes, are so-called cosmogenic isotopes. So there's the word cosmogenic. What that means, is these isotopes are produced by cosmic rays. Now, cosmic ray is a rather old term and it's not an accurate term. There's no such things as rays and ray guns, okay. Cosmic rays are actually ions. They’re charged particles, just like the particles in our accelerator. However, these particles have been made in the much bigger accelerators in the sky, that are out there in the distant reaches of the universe. Events like, well, we don't fully understand it, but a supernova explosion. So the merger of compact stellar objects and so on. The important point is that the earth has been continuously bombarded by these cosmic rays, day in, day out. And this diagram here, shows a primary cosmic ray. So that's one of these very energetic particles entering the Earth's atmosphere. Now, while these particles are traveling through the vacuum of space, they travel unimpeded, but once they start to enter the Earth's atmosphere, they begin to have collisions with the nuclei of the atmospheric gases. And that causes a nuclear reaction to take place, which produces secondary particles. You can see the secondary particles coming up, they in turn are terribly energetic, they cause tertiary reactions and so on. So you get this great cascade of events happening in the sky that produce these cosmogenic radionuclides, and others, I mean, these are just some. You can see carbon-14 there with a half life for 5,730 years, you can see beryllium-10, with a half life of 1.4 million years. And also aluminium-26, chlorine-36 and iodine one two nine. So those are all commonly used. You'll see, in this diagram that some of these secondary particles are energetic enough to make it down into the surface of the earth or indeed into ice sheets. And the process continues. So they continue to produce cosmogenic radionuclides in the surface of the Earth. And my colleague here at ANSTO, David Fink, he specialises in the so-called cosmogenic dating. So what they do, they take samples of rock and they grind it up And they separate the minerals, often they're looking for quartz, but not necessarily quartz. They dissolve that quartz and they can separate the aluminium-26 and the chlorine-36, even the carbon-14 and the beryllium-10 that's produced in the rock structure itself. And this is a clock. This is a clock in itself. So it's just like a radiocarbon clock, but it's an accumulating clock. So what, for example, if you've got the case where you have a glacier, glacier has been flowing down a valley, and of course, as the glacier flows down, it erodes the bedrock underneath it. And it basically, zeroes the bedrock. Now, if there's a climate change event and that glacier starts to retreat back up again, the ice is no longer overlying that zeroed bedrock. And so the cosmogenic clock can start. The ice produced, it works like a shield from the cosmic radiation. Once the ice is gone, the cosmogenic clock in the rock starts to tick. And these radionuclides start to build up in the rocks. So if you can take your samples in the field, bring them back to your laboratory, go through this rather complicated process to extract the atoms that have been generated inside that rock, put it into your particle accelerator and count them, you can work out how long ago that ice retreated. You can do the same kind of trick with avalanches, you know, wherever there's an exposed rock surface. Tsunamis, okay, transport big boulders, flip them upside down. The unshielded part of the rock was exposed.

Chris: The ticking of that clock? Is that something that when you have some of these large geological events, that then scientists immediately will start to spring into action in order to, as a new data source, is that something that they will be looking for?

Dr Smith: Until this technique, this cosmogenic dating technique was developed, geologists had no way of dating these kinds of events. There just simply wasn't a way to do it. So this is really revolutionising geomorphology. You know, you're able to actually put a time to, you know, to these geological processes that can be long and extent, and might've happened a very long time ago and we simply had no way of doing that previously.

Chris: I suppose, in terms of the timing of these events, I'm always challenged by this description of events in Earth's history as being referred to as ancient or recent. And I'm looking at the ice core histories that are provided, are sort of listed in that more recent geological history, even though they are, you know, up to 800,000 years prior. Is this other methodology, is that intended for further back in the past than that? Or is it overlap with the area of Earth's climate history that would be studied in ice cores?

Dr Smith: Well the ice core record goes back about, the longest ice core record is about 850,000 years. So certainly the useful, very useful part of the record is about 800,000 years in duration. The cosmogenic dating is useful back through the quaternary. So that's the last 2 million years or so. But if you want to actually date rocks that are much older than that, you have to use other radiometric techniques, you know, potassium, argon dating, and so on, but certainly they hope to get a core that's at least a million years old, if not 1.5 million years old. And one of the primary or scientific objectives for that, is to see how the glacial-interglacial period density has changed, back around a million years. Because for the last six or seven glacial cycles, each glacial cycle has been about a hundred thousand years, but there's reason to believe that the interglacial and glacial cycles were of much smaller duration prior to that, and we don't really understand why.

[Slide reads: Climate signals archived in polar ice sheets: air, cosmogenic isotopes, micrometeorites, chemicals, metals aerosols. Several images show snow, ice, and layers of ice in an ice cliff, another image shows how at increased depth snow turns into porous firn and into ice with air bubbles. Further images show the process of firn air extraction, a bucket of ice cores and a instrument of analysis]

Chris: An important question for students studying earth and environmental science is around that. How does studying ice cores help us understand climate variation in the past?

Dr Smith: Antarctica is the coldest, windiest, driest, largest continent on the planet. And yet, even though it's the driest continent on the planet, it has 70% of the Earth's fresh water locked up as ice. So the ice sheets in Antarctica are thick, they are anywhere between three and four kilometres thick. They're so heavy, they actually push the rock down. And in some cases the rock underneath the ice has been pushed beneath sea level. So, Antarctica mostly is drier than the Sahara desert. So how can it be that most of the world's fresh water is there? The answer of course, is that it's very cold. So even though it's dry, the small amount of snow that does fall, doesn't melt, it accumulates and it builds up in layers. Now these layers aren't always visible, but if you have a look over at this shot here, this is a pretty dramatic photo of an ice cliff somewhere or other, I'm not sure where it was, but you can see very clear layering there as you go down and down and down. And that's the basic idea. As you go down from the surface, deeper and deeper, you're basically going back in time, which is great. As long as you've got the depth timescale, if you don't have the depth of timescale, you got nothing. So, you know, you could take a drill to Antarctica, you could drill down a hundred meters and take up some snow and go “Oh look I've got some old snow. I wonder how old it is.?” And this is where my colleagues come into play. The snow falls in Antarctica and it constantly builds up and it builds up and it builds up and up on the surface it's snow, obviously down deep it's ice. But until you get to that point there's a region of compacting snow, which is still porous, that we call firn. So that's F-I-R-N, firn, and up on the surface, the firn is quite porous and it's quite light, it weighs about half a gram per cc. Whereas water, of course, has got a density of one gram per cc. But as the weight of the snow, or the firn, builds up, all snow particles become compressed together. They become sintered. And the air that is trapped in between those snowflakes gets compressed. And at some point they get compressed off into bubbles. They get closed off. Now from that point, the bubbles move with the ice. But what people often don't realize is that the air that's enclosed in those bubbles there, is always younger than the ice that encloses the bubbles. And that's because of this process here. (image of snow versus depth, showing snow at the surface, firn from about 10-25m depth and firn becoming ice at 60-110m depth). So the depth at which this close-off occurs, you can see over on this axis here I've shown it to be anywhere between 60 and 110 meters beneath the surface, at Law Dome, which is the site that I frequently go to in Antarctica, because it's a great site, that depth is around about 80 meters. So, you know, that's quite a long way down. Once you're below 80 meters, you've got basically bubbles, but until you get to 80 meters, you've got a diffusion column okay, it's a porous column. And strictly speaking, the air that's in these little pockets here, that haven't quite closed off yet, is still in contact with the atmosphere here. So there are these diffusion processes taking place. And that's where I am totally reliant upon my colleagues in the Australian Antarctic division. 'Cause my colleagues in the Australian Antarctic division, well they do all the things, but in particular, they measure the water isotopes. So water H two O. How do you get the gas samples out of the snow pack, where they're in? Well, what you can do, when you're in the upper 80 or so meters, the firn region, what you can do is drill a hole to a certain depth, take your ice drill out, and then put in basically a big rubber plug that you drop down into the hole and you blow it up and you seal off the hole. And then from beneath that plug, you can start to pump out air, now that air comes from a pretty narrow horizontal region around the bottom of the hole. And this is a, an example of, of some firn air extraction. So, this is called firn air, and it's possible to pump out quite large volumes of firn air relatively easily from the solidifying snow. We typically are able to collect hundreds of litres of air from each level, which is enough to do our work. But as you go deeper and deeper into the ice sheet, things get much trickier because here you've only got bubbles. So basically you have to bring the ice up from down beneath, and then you have to extract the air from the bubbles. The problem is there's only about a hundred millilitres or about a 10th of a litre of air in each kilogram of ice. And for the kinds of studies that we do, even though we're using this really sensitive technique of accelerator mass spectrometry and atom detecting, atom counting technique, we still need to bring about a tonne of ice up to the surface and melt it in a big vessel like this in order to get the air out. And form a sample like that, we will typically extract about a hundred litres of air. Something like that.

Chris: To get one tonne of ice, if it was over a very large variation in depth, and that would, you'd lose some of that time resolution that you would be looking for. Do you have to drill multiple holes in order to obtain the right amount of ice and maintain that fixed period of time?

Dr Smith: There are, there are two different kinds of ice sheets if you like. The ice sheet that I've described here is, is an accumulating ice sheet, okay. Where it's always been at added to. Of course, as the snow compresses the ice, it flows plastically out towards the margins of Antarctica and ultimately breaks off as icebergs. In order to get old ice from a site like this, it's a real challenge to get enough ice And, so that show that you were referring to, the Foreign Correspondence show, the Atom Hunters, and we drilled to a total depth for, I think it was, 235 meters there. So these are quite shallow, ice cores compared with some, like C, the Dome C core, I was telling you about before, you know, that that was 3.2kilometres. So 3,200 metres down. So we're only going to 235 metres to get our samples there. So we're trying to go at that particular site that took us back to about 1830 A.D., so just before the start of the industrial revolution, which was our goal. Okay. But we had to take up three parallel cores at that site to get enough ice. With the biggest drill, that could drill to that depth, which is a four inch drill, sorry to use these terms, So 10 centimetre drill. So as the ice flows over the bedrock towards the surface, it comes up. So first of all, the ice is flowing down and then it starts to flow out horizontally. And if you're at the right site where there's not much accumulation, there's quite a lot of wind and a little bit of sun, what can happen is that ice sublimes. So sublimation as all the students listening will know is when a solid goes directly from solid to gas without going through the liquid phase. And that happens in Antarctica. And so what happens is this ice is being pushed up from below, and at the same time, it's subliming away. And the net result of this is that you can actually, at these kinds of sites, you can access it very, very old ice at the surface, close to the surface. And we, our team, developed this ice drill specifically for that reason to access the biggest diamond of core that we could. So we could minimise the length to get the mass that we needed to do our studies. And in particular, at sites like this, these blue ice zones, where this drill doesn't work terribly deep, you can access this ice close to the surface. Again, before we can do this, you've got to map the whole area out. You've got to work out how the ice is flowing. You've got to work out the chronology of the area, but once you've done that, if you've got a big drill, it's possible to get a tonne of ice, ancient ice, from quite close to the surface. So I actually joined an expedition with my American colleagues at Taylor Glacier, which is just near the Ross ice shelf near the American research base, McMurdo and the New Zealand base, Scott base, they're both in the same location. And that's exactly what we were doing. So we're using this big blue ice drill, it's called the Bid, B-I-D, to access ice on the Taylor Glacier, in the dry valleys near McMurdo. And we were pulling up ice that was 50,000 years old, that was only five meters beneath the surface at this site. So, you know, I've obviously spoken a lot about my colleagues, I've spoken about my American colleagues, who are primarily based at the University of Rochester in New York State. My CSIRO colleagues in Aspendale in Nolan, a suburb of Melbourne. My Antarctic division colleagues who are in Hobart and Tasmania, and there are others. Also, I have New Zealand colleagues, but the point is all these people bring together their particular skills and expertise. And the sum of the whole is greater than the sum of the parts. And I bring my particular expertise. So I'm not, I'm not a climate scientist, I'm not an environmental scientist. At the end of the day I'm a physicist. I play with accelerators. I like playing with accelerators. I also like going into the field and doing exciting things. And, you know, none of us could have been done this kind of work alone. And I've been working closely now with most of these people for 20 years, finding problems, overcoming problems, developing trust in each other, and in each other's abilities, in the quality control in each other's labs. That's what makes this kind of research possible. It's possible to make your paths. Now, when I was at school, I've always been interested in science and chemistry and mathematics. And when I was in kindergarten, I think my kindergarten teacher gave me the nickname, the professor. So she must've seen some kind of a spark there back in the early days, but I must say I've never, I only ever followed my interests in my education. So, when I finished school, it was clear that I was going to go to university and that I was going to study science and I studied obviously physics and I studied chemistry and I studied mathematics. So I was also very interested in electrical engineering, but you’ve got to draw the line somewhere. And well, I thoroughly enjoyed mathematics and I was quite good at mathematics, but I wasn't brilliant at mathematics, not, in my opinion, brilliant enough to make a career of it. And while I was going through my undergraduate course at university, I took the opportunity to do, what we called, vacation scholarships with some of the research labs there. And I ended up working in one, well I did it for three years, but the one that captured my interest was when I worked for the materials irradiation group at the University of New South Wales. They had Sir Ernest Titterton’s old 1.4 million volt Cockroft-Walton accelerator set up in a tram shed off-campus. So did my apprenticeship there, if you like, and after I'd been doing that for a few years, I thought, well, I should really do something with this. I should do a PhD. So I did a PhD on the ion accelerator that I built while I was there. And it's really, you know, that those early days gave me the skills and the interest to end up applying for the job here at ANSTO.

Chris: What you call our depth studies and also the new science extension course really puts students in the hot seat when it comes to asking questions and exploring other aspects of the world in a little bit more depth than we normally would go into. Many students are challenged by the idea of asking questions and trying to decide what it is they should or what's worthwhile exploring. Do you have any advice for students in that position who are really looking to find something worth investigating?

Dr Smith: There is no such thing as a trivial question. And you know, when I hear somebody say, “Oh, that's trivial”. I'll think to myself, “nah, that's not trivial. You just haven't thought about it deeply enough”. Every question is worth asking. Even if you feel it might be trivial, you're probably wrong. You probably just haven't looked at it carefully enough. So never be afraid to ask questions, never lose your sense of curiosity. I guess that's one of the things that, you know, always kept my life interesting and exciting. I'm naturally curious. And I hope I never lose that. I'm very curious after we complete this conversation to go and see what the hell's going wrong with my accelerator, which is actually running in the next room right now, but it hasn't been on for six months. And not surprisingly, after being off the air, you know, a big, complicated machine being off the air for six months, it takes a while to get things going. So, I mean, it's a nuisance that it's not, just can't turn it on and everything works. And if you don't understand something, don't pretend that you do, ask. People would much prefer to be asked to explain something than for you not to understand what they're talking about.

(gentle music) (soft chime)

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