“URANIUM: let’s talk about it”

Script to accompany informational video

00:04 There is something about uranium! What is it, what is it used for, and how does it do what it does? There are questions about whether we should be mining it in Saskatchewan, and about how it is used to produce energy. So let’s talk about it.

00:20 Northern Saskatchewan is one of the richest sources of **uranium**. This heavy, long-lived, radioactive metal has been mined and used in various ways for close to one hundred years. Questions come up about the environmental impacts of the mining and waste management processes, about the ways uranium is used, and about the risks associated with the spread of nuclear materials around the world.

00:45 So what is uranium good for? In nature, uranium is found mixed up with another radioactive element, **radium**, and it was the radium that was initially of greatest interest. Because it glows in the dark, radium was used early in the 20th century for painting the numbers and the hands on watch and clock faces so you could tell the time in the dark. Uranium itself had a decorative use too, in glow-paint for pottery. This was all before people understood the health hazards associated with these materials.

However the big breakthrough for the uranium industry came during World War 2 when the development of atomic bombs led to a major expansion of the industry. During the Cold War that followed World War 2, nuclear weapons were the main driver for uranium mining. Northern Saskatchewan’s mines operating during the 1950s and early 1960s were largely tied to this application.

But since production of electricity from nuclear power became a reality during the second half of the 20th century, uranium’s major use has been as fuel for nuclear power reactors. This has not been without controversy.

02:03 To understand the issues and concerns that have accompanied the mining and use of uranium, we need to review the basic features of the whole sequence of steps that take us from mining to electricity production and waste management.

02:19 So let’s begin with some basic physics. Think of the classical picture of the **atom** – a core made up of positively charged **protons** and uncharged **neutrons**, with **electrons** circling around it like planets around the sun.

02:34 Each chemical element is defined by the number of protons in it’s **nucleus**. For example, a hydrogen atom has only one proton, uranium has 92.

02:45 But many elements can exist in different forms depending on how many neutrons their atoms contain. We talk about different **isotopes** of an element – for example, almost all naturally occurring hydrogen has no neutrons in its atomic nucleus. But there is an isotope of hydrogen, known as deuterium, that has one neutron in its atomic nucleus, and another isotope, tritium, that has 2 neutrons.

All of these isotopes of hydrogen behave the same way chemically. But they have different **radioactive** properties. I’ll explain what that means in a moment.

03:27 So what do we mean by **radioactivity**?

Radioactivity is what happens when an atomic nucleus is unstable and undergoes changes to turn itself into a more stable kind of atom. Some isotopes of some elements are unstable and they naturally, continuously, throw off part of their nuclear core or energy in a process known as **radioactive decay**.

03:54 Just what these atoms throw off can come in different forms. Some of them throw off **alpha particles**. These are little chunks of the nucleus made up of 2 protons and 2 neutrons.

Alpha radiation is very interesting because when an alpha particle is thrown off by an atomic nucleus, the nucleus loses 2 protons. And because the identity of a chemical element depends on the number of protons in the nucleus, the atom becomes one belonging to a different chemical element. So an actual chemical change has taken place.

The alpha particles that are emitted are relatively large as nuclear particles go, so they can't penetrate very far. If you hold a sheet of paper over an alpha-emitting material, the radiation can't get through it.

But this doesn't mean that it's not dangerous. If it somehow gets inside your body it can do lots of damage. It can sit there and irradiate your organs from inside for a long time. More on that later.

04:55 Other unstable isotopes emit **beta-particles**, which are negatively charged electrons that have been stolen from neutrons, thus changing a neutron into a positively charged proton. That's **beta radiation** and it also results in a change from one element to another. Now we have an atom of an element with one more proton than the original one.

Beta radiation is not as easily shielded as alpha radiation. Something like a cookie sheet will be needed to stop it in its tracks.

05:29 The third kind of radioactivity, **gamma radiation**, doesn't result in a change into a different element. It's just a way that an atom gets rid of excess energy from its nucleus. Gamma radiation, like X-rays, is very penetrating, and this is where you need lead shielding for protection.

These processes of **radioactive decay** take place continuously and at very different speeds. Some decay processes are very fast, others very slow.

06:00 We define the **half-life** of a given nuclear decay process as the time it takes for half of any given quantity of the particular atoms to decay. So, if you're told that the half-life for the radioactive decay of the carbon 14 (C^{14}) isotope of carbon is 5,730 years, you know that after 5,730 years half of the original C^{14} atoms will have turned into Nitrogen 14 through beta decay, and that in the following 5,730 years half of the remaining ones will make the change, and so it will go on indefinitely. The C^{14} never totally disappears.

Actual half-lives range from fractions of a second to many thousands of years.

06:47 Sometimes it takes more than one decay process for an isotope to reach a stable state. So we find that many heavy atoms undergo a long sequence of decay steps, each with its own half-life.

07:00 So, for example, let's look at the most common isotope of uranium, $\mathbf{U^{238}}$. Incidentally, the 238 in its name means that the total number of protons plus neutrons in its atom is 238. Of these, 92 are protons and the rest are neutrons. This isotope first undergoes a very slow alpha decay with a half-life of 4.5 billion years. This process results in the formation of an isotope of thorium, thorium 234. The nucleus has lost 2 protons and 2 neutrons. Thorium 234 then goes through two beta-decays with relatively short half-lives to uranium 234, which then undergoes a slow alpha decay to thorium 230.

Further alpha decay with an 8,000 year half-life takes it down to radium 226. This is why we always find radium mixed up with the uranium when uranium ore is mined.

This series of decay continues through many further steps until finally it arrives at a stable form of lead. So whenever we find uranium, we also find a mix of all of these so-called radioactive decay products. So that's the natural decay process for the commonest form of uranium.

08:24 A separate process we need to understand is **nuclear fission**.

A few isotopes of the heavy elements can be smashed into pieces by hitting them with neutrons at just the right speed. This is called **nuclear fission**, and these isotopes are described as being **fissile** (which means splitable). The fission process results in the release of a great deal of energy as the nucleus breaks up.

08:50 The commonest isotope of uranium, **U238**, is not fissile, but **uranium 235**, which makes up just **0.7%** of natural uranium, is. This is the isotope that is therefore of great interest for energy production.

09:07 In reality there will be many more than two smaller atoms formed. These pieces that result from the splitting of the uranium atom are called **fission products**. They are mostly very unstable, very radioactive isotopes of lighter elements.

In addition to these fission products, the fission process results in the release of more neutrons that then go on to crash into other uranium atoms, leading to a **chain reaction**.

As each uranium atom splits, some mass is turned into energy, so a huge amount of heat and radiation is produced along with the fission products.

The fission chain reaction may proceed in one of two ways. If we don't control the number of neutrons that are flying around, the chain reaction will become an explosion as energy is released very fast. This is what happens in an atomic bomb.

10:00 But if we want to tame the release of energy to use it for **power production**, we need to get rid of some of the excess neutrons by absorbing them before they have a chance to split more atoms. The heat produced by the fission process can then be used to boil water to generate steam which produces electricity in the same way as a coal-burning power station does.

10:22 So here's a simple sketch of the nuclear fuel cycle, starting on the left side with the **mining** of uranium ore, then the **milling** and **refining** of the ore to remove most of the impurities before the uranium is made up into **bundles** to fuel nuclear reactors. In some cases there's an intermediate step called **enrichment**, in which some of the uranium 238 is removed so that there's a higher concentration of uranium 235, which some reactor systems require. After a certain amount of the uranium in the fuel bundle has fissioned, the process slows down, and we're left with so-called used fuel, or **nuclear fuel waste**, which contains a highly radioactive and toxic mix of fission products as well as other very long-lived, hazardous materials. Decisions need to be made about how this dangerous stuff will be looked after for the next ten thousand years or more. So the whole nuclear fuel cycle is producing at least three kinds of dangerous wastes. There's the waste rock from the actual mining operation. This contains varying levels of many toxic contaminants. Then the milling operation produces **tailings**, which contain the radioactive and chemically hazardous substances that are brought up from underground along with the uranium. **Depleted uranium** is a by-product of the enrichment process – it is mildly radioactive and may be destined for use in hardening traditional bullets and shells. The nuclear fuel waste from energy production in a nuclear reactor is the big problem for which no really satisfactory solution has been found. The very long period for which it remains hazardous means that we should be planning for a way to keep it out of the ecosystem for a time span longer than all of human history. Humans have no experience in designing or building anything to last for such a long time period.

12:20 So let's just review the part of the process that takes place in Saskatchewan.

12:25 We start with the mining. Some of this is **open-pit** mining, where the ore is dug out directly from the surface, leaving a big, bowl-shaped hole with tracks running around inside it for the vehicles bringing the ore up to ground level. Other mines are deeper, **underground** mines, which are accessed via a shaft. In either case, a good deal of waste rock that overlies the ore gets piled on the surface beside the mine. Much of this rock contains toxic and acid-generating materials.

The ore itself contains not only uranium, but also all those radioactive decay products that we looked at earlier, and other hazardous materials such as arsenic. The milling process basically separates the uranium from much of the unwanted stuff and turns the uranium into a yellow **uranium oxide** product known as **yellowcake**. Milling generally takes place close to the mine sites.

13:20 This is an old photo of one of the old open pit mines and the adjacent mill operation that was active in the 1960s.

13:30 The radioactive and toxic contaminants left behind from the milling process are called **tailings**. They generally have a sand-like texture and colour. In the early days the tailings were just dumped on the ground or into nearby lakes. Now they are usually moved by pipeline from the mill to some kind of nearby disposal site in the form of a wet slurry.

13:50 The current disposal practice in Saskatchewan is to store these tailings in conical pits under water. Liquid waste from the mill, known as **effluent**, is treated chemically to reduce its contamination to an allowable level, then released into surface waters. This generally means that it goes into the first of a chain of connected lakes, with much of the remaining contamination ending up in the sediment at the bottom of the first lake.

14:16 Let's look at where this is taking place in Saskatchewan. The big lake up in the north-west corner is **Lake Athabasca**. The early uranium mines were close to the north shore of the lake. The currently operating ones are a bit further south, in the area to the west of Wollaston Lake, which is the big lake south and east of Lake Athabasca. There are no big communities in this part of the province, and very few roads, but there are still people living in small communities, some of them making a living by hunting, fishing and trapping. The safety of the environment and the purity of the water is very important to them.

14:54 This is a photo of a tailings pit currently in use at **Key Lake**. The water covering the tailings provides shielding from the radiation emitted from the uranium and its decay products. One of the problems encountered at this site has been the soft sand of the pit walls collapsing into the water. Given that the tailings will remain hazardous for thousands of years, concerns have been raised about whether the contamination will remain confined to the pit. There are also issues about birds landing on the pit water surface and becoming contaminated – to them it looks like a nice little lake.

15:32 And this aerial photo shows the abandoned site of the **Gunnar** mine, right on the shore of Lake Athabasca. This mine ceased operation in the early 1960s, leaving behind a host of environmental problems. The roughly circular water body near the centre of the picture is the open pit mine, now flooded with contaminated water. The pale, sand-coloured area above it is where tailings were dumped and left unprotected. And the two big, flat-topped, grey piles occupying most of the middle of the picture are contaminated waste rock. The waste rock, the tailings and the flooded pit are transferring contaminants into Lake Athabasca. Plans are being developed for a partial, very expensive clean-up of the site, but it is well understood that it will not be possible to make the area safe for year-round habitation, and that adjacent bays in the lake will remain contaminated for all the foreseeable future.

16:28 Other abandoned uranium mines have similar stories to tell. This map shows part of Lake Athabasca. Just below the little red google arrow that locates **Uranium City** you'll see a lake – this is **Beaverlodge Lake**. Beaverlodge Lake has received the contaminants from many old mine and mill sites that were not responsibly managed during their operation and after they ceased operation.

In all, five watersheds leading into or out of Beaverlodge Lake have been left contaminated with radioactive and toxic chemicals, another problem left for future generations to try to clean up. These watersheds are shown by the colored areas surrounding the lake and to its north-east. You can see how northern Saskatchewan is covered with thousands of inter-connected lakes and streams so it's very hard to prevent the contaminants from spreading through the waterways.

17:15 Let's look now at what happens to the uranium after it leaves Saskatchewan.

So the milling process in Saskatchewan has converted the ore to the **uranium oxide** product, **yellowcake**.

This is trucked to Ontario for further processing.

And is then made up into **fuel bundles** that fit into metal canisters for use as reactor fuel.

17:44 In the reactor, **nuclear fission** takes place and some of the uranium turns into **fission products**, **heat**, and another element called **plutonium**.

The plutonium doesn't result from the fission process, but rather from the absorption of neutrons by some of the uranium 238 atoms that make up the bulk of the natural isotope mix.

Remember that it's only the scarcer uranium 235 isotope that undergoes fission. Uranium 238 is not fissionable, but it can capture neutrons and turn into an isotope of **neptunium** that in time decays into plutonium.

18:23 So the used fuel from the reactor contains not only some remaining uranium and the fission products, but also plutonium.

Plutonium is of interest because it can itself be used as reactor fuel, or, more worryingly, as nuclear bomb material. This is why there's a lot of nervousness about the possible diversion of nuclear fuel to countries or terrorist organizations that could misuse it.

18:49 There's another military application of a uranium by-product that we should mention. That is **depleted uranium**.

Earlier we mentioned that many reactor systems require a uranium fuel that has been enriched in uranium 235 content.

The enrichment process results in the creation of a waste product called depleted uranium.

When we sell uranium to the United States for use in their power reactors, it is enriched, and the depleted uranium goes into a stockpile.

This depleted uranium is a heavy, slightly radioactive material that is used for coating military bullets and shells to make them harder and more penetrating. So even when we say we only sell uranium for peaceful use, we cannot guarantee that some of it doesn't end up on a battlefield.

19:37 Now let's look briefly at the management of the used nuclear fuel when it's no longer useful for power production.

After the uranium fuel has been in the reactor for a while, and much of the uranium 235 has undergone fission, the fuel bundle is no longer efficient and has to be replaced. Each bundle of used fuel contains uranium, fission products and plutonium.

When the used bundle is first removed from the reactor it is extremely radioactive and dangerous to handle. The level of radioactivity is so high that if you stayed close to it for even a few minutes you would get a fatal dose of radiation.

For the first few years following removal of used fuel from the reactor, most of the radiation is coming from the relatively short-lived fission products.

20:27 During this period the fuel bundles are handled remotely so operators don't have to get close to them, and they are stored under water in **big tanks** that look like swimming pools.

After several years, a lot of the short-lived fission products have decayed and are less radioactive. At this point the fuel bundles are generally moved into **dry storage** in concrete silos on the reactor site.

Now, the problem is that the long-lived components of the used fuel are going to be a hazard for tens of thousands of years, so we are faced with a huge long-term management problem.

This is complicated by the fact that there is some interest in keeping open the option of eventually recovering the plutonium from the fuel waste; this would be a very hazardous process and one that opens the door to potential harmful uses of plutonium.

21:20 The reason that it's so important to keep these radioactive materials away from people and other living things is that ionizing radiation can have a number of harmful effects on living cells.

21:33 So what kind of damage can it do?

It can potentially cause **cancer**,

it can make an unborn baby **develop abnormally**,

and it can **create genetic changes** that can be passed on to future generations.

21:46 So how big a risk is it? We're all exposed to some level of background radiation. The question is, how much is too much?

21:55 We can't actually define a safe level of ionizing radiation. Governments set standards for public safety and nuclear worker safety that they consider are low enough to adequately protect us. But actually you can't say that a particular dose level is "safe". Generally, the less exposure the better.

But it's complicated by the fact that some kinds of radiation are more harmful to living cells than other kinds are. Alpha radiation is particularly damaging.

But the good thing is that because alpha radiation doesn't penetrate very far, it can hurt you only if it actually gets inside your body.

This can happen if you breathe in an alpha-emitting material, or accidentally eat or drink it, or if it gets into a wound.

22:42 The challenge of coming up with a safe way of keeping nuclear wastes out of the environment for the necessary thousands of years is extremely difficult. And we wouldn't be able to avoid the problem just by stopping use of nuclear power. We have to deal with the wastes that have already been created over the past 50 or 60 years and that are still in temporary storage. So let's look at what Canada is planning to do.

23:06 Planning is in the hands of an agency called the **Nuclear Waste Management Organization**.

They are looking at what they call an adaptive phased management plan. This means that there will be several stages in the process, with decisions being made along the way as needed.

The first stage is to continue storing the wastes on the reactor sites.

After 10 years or so the fuel bundles would be moved to a site most likely in Ontario. This is one of 4 provinces that are involved in the uranium and nuclear power production industries. The other 3 are Quebec, New Brunswick and Saskatchewan.

At the central site, the material would initially go into temporary storage, possibly in a shallow underground area.

Finally it would be transferred to permanent storage in deep underground vaults that would eventually be sealed up.

23:58 They're still keeping open the option of leaving the vaults unsealed for an indefinite period so that, if necessary, the hazardous wastes could be removed. This might happen, for example, if the waste containers started to leak and the wastes needed to be re-packaged.

It could also happen if, at some future time, people want to re-process the wastes to extract the plutonium from the waste.

This re-processing is a hazardous chemical process involving dissolving the wastes in nitric acid. Communities considering accepting a nuclear fuel waste facility should be aware of the possibility that it might eventually involve a re-processing operation.

24:38 As of 2015 things are still at the stage of seeking a suitable site for a waste management facility.

The Nuclear Waste Management Organization is looking for a willing community – one that is convinced that the benefits of hosting such a site will outweigh the problems.

Meanwhile, it's going to be several decades before there will be an actual, operating waste disposal facility in Canada.

25:03 So this has given you an introductory look at the role of Saskatchewan's uranium industry and how it is linked to other parts of the nuclear fuel cycle.

If you'd like to pursue the questions further, please contact the **Saskatchewan Environmental Society**.

www.environmentalsociety.ca