On a december afternoon in chicago during the middle of world war two scientists cracked open the nucleus at the center of the uranium atom, and turned nuclear mass into energy, over and over again.

They did this by creating for the first time a chain reaction inside a new engineering marvel, the nuclear reactor.

Since then the ability to mine great amounts of energy from uranium nuclei has led some to build nuclear power as a plentiful utopian source of electricity.

A modern nuclear reactor generates enough electricity from one kilogram of fuel to power *an* average american household for nearly thirty four years. But rather than dominate the global electricity market nuclear power has declined from an all time high of eighteen percent in nineteen ninety six, two eleven percent today.

And it's expected to drop further in the coming decades. What happens to the great promise of this technology. It turns out nuclear power faces many hurdles, including high construction costs and public opposition. And behind these problems fly a series of unique engineering challenges.

Nuclear power relies on the vision of uranium nuclei and a control chain reaction that reproduces this splitting in many more nuclei.

The atomic nucleus is densely packed with protons and neutrons, bound by a powerful nuclear force.

Most uranium atoms have a total of two hunter thirty eight protons and neutrons, but roughly one in every one hundred forty, *laps* three neutrons, and this lighter isotope, is less tightly bound.

Compared to it's more abundant cousin, a strike by a neutron easily splits the u *to* thirty five nuclei into lighter radioactive elements called fission products, in addition to two to three neutrons gamma rays and a few neutrinos. During vision some nuclear mass *transforms* into energy. A fraction of the *newfound* energy powers with fast moving neutrons, and if some of them strike uranium nuclei vision results in a second larger generation of neutrons. If this second generation of neutrons strike more uranium nuclei more efficient results in an even larger third generation, and so on. But inside a nuclear reactor this spiraling chain reaction is *teamed* using control rods, made of elements that capture excess neutrons and keep their *number* in check.

With a control chain reaction a reactor draws power steadily and stably for years. The neutron *lead* chain reaction is a potent process driving nuclear power, but there's a catch that can result in unique demands on the production of it's fuel. It turns out most of the neutrons emitted from fission have too much *it's* kinetic energy to be captured by uranium nuclei. The *fission* rate is too low, and the chain reaction fizzles out. The first nuclear reactor built in chicago used graphite as a moderator to scatter and slow down neutrons just enough to increase their capture *buy* uranium and raise the rate of vision. Modern reactors commonly used purified water as a moderator, but the scattered neutrons are still a little too fast.

To compensate and keep up the chain reaction the concentration of *you* to thirty five is enriched to four to seven times *it's* natural abundance. Today enrichment is often done by passing a gaseous uranium compound through centrifuges to separate lighter you to thirty five from heavier you to thirty eight.

But the same process can be continued to highly enriched you to thirty five, up to one hundred thirty times it's natural abundance. And create an explosive chain reaction in a bomb.

Methods like centrifuge processing must be carefully regulated to limit the spread of bomb grade fuel.

Remember only a fraction of the released vision energy goes into speeding up neutrons, most of the nuclear power goes into the kinetic energy of the fission products.

Those are captured inside the reactor as heat by a coolant, usually purified water.

This heat is eventually used to dry an electric turbine generator by steam just outside the reactor. Water flows critical not only to create electricity, but also to guard against the most dreaded type of reactor *accidents*, the meltdown.

If water flow stops because a pipe carrying it breaks or the pumps that push it fail, the uranium heats up very quickly and melts. During a nuclear meltdown radioactive vapors escape into the reactor and if the reactor fails to hold them, a steel and concrete containment building is the last line of defense. But if the radioactive gas pressure is too high containment fails and the gases escape into the air, spreading as far and wide as the wind blows.

The radioactive fission products in these vapors eventually decay into stable elements.

While some decay in a few seconds, others take hundreds of thousands of years. The greatest challenge for a nuclear reactor is to safely contain these products, and keep them from harming humans or the environment.

Containment doesn't stop mattering once the fuel is used up, in fact it becomes an even greater storage problem. Every one to two years, some spent fuel is removed from reactors, and stored in pools of water that cool the *waist* and block it's radioactive emissions.

The irradiated fuel is a mix of uranium that failed to vision, vision products, and plutonium, a radioactive material not found in nature.

This mix must be isolated from the environment until it has all safely decayed. Many countries proposed deep time storage in tunnels drilled far underground. But none have been built, and there is great uncertainty about their long term security. How can a nation that has existed for only a few hundred years, *planted* guard plutonium through it's radioactive half life of twenty four thousand years. Today many nuclear power plants sit on their waste instead, storing them indefinitely, *on site*.

Apart from radio activity there's an even greater danger with spent fuel. Plutonium can sustain a chain reaction, and can be mined from the waist to make bombs.

Storing spent fuel is thus not only a safety risk for the environment, but also a security risk for nations.

Who should be the watchman to guard it.

Visionary scientists from the early years of the nuclear age pioneered how to reliably tap the tremendous amount of energy inside an atom.

As an explosive bomb, and as a controlled power source with incredible potential. But their successors have learned humbling insights about the technology's not so utopian industrial limits. Mining the subatomic realm makes for complex, expensive, and risky engineering