ACCELERATORS FOR AMERICA'S FUTURE

Fermilab

Energy and Environment

Accelerator Driven SubCritical Systems (ADS)

A novel approach to Nuclear energy and waste management

Jean Delayen*, Yousry Gohar ‡ , Rajendran Raja† and Alex Stanculescu§

Summary of WG3/WG4 Fermilab Workshop AHIPA09

Motivation

Currently, we emit 7 Billion tons of carbon into the atmosphere every year. By 2055 this is expected to rise to 14 billion tons. If nothing is done, global warming will play havoc with drinking water supply to millions (in ~30 years), cause flooding, pestilence, hurricanes and cause loss of arctic ice and coastal cities in 50-100 years. If we reduce the rate of increase of carbon in the atmosphere by 1/7 using nuclear power, this will mean doubling the total of the earth's nuclear power by 2055.

Conventional nuclear reactors only use less than 0.7% of the total uranium that is mined. The Uranium 235 thus burned will not be replaced. In addition, nuclear reactors produce waste that has to be stored away for geological periods of time. Nuclear reactors operate very close to criticality. The critical condition (k=1) is achieved when neutrons are produced by fission at a rate that equals the number lost by absorption and leakage. When k>1, an uncontrolled chain reaction takes place.

The scheme we propose uses an accelerator to supply fast neutrons(~10MeV) into a nuclear reactor. It simultaneously produces power, burns away nuclear waste (waste as fuel) and permits additional sources of fuel such as Thorium-232 and Uranium-238. In addition, it is operates at sub-critical conditions, which enhances the safety performance.

Thorium 232 as fuel.

Thorium 232 absorbs a fast neutron and converts into Thorium 233. This decays into protoactinium which further decays into Uranium 233.

$$^{232}Th + n \Rightarrow {}^{233}Th + \gamma \xrightarrow{(22m)} {}^{233}Pa + \beta^- \xrightarrow{(27d)} {}^{233}U + \beta^-$$

Uranium 233 is fissile. We have transmuted Th232 into an element (U233) which fissions and gives us energy.

- After ~ 5 years of running, fission products should be removed and more thorium added and the actinide materials returned to the reactor for burning.

Uranium 238 as fuel.

$$U^{238} + n \rightarrow U^{239} + \gamma$$

$$U^{239} \rightarrow Np^{239} + \beta^- \ (23.4\text{m})$$

$$Np^{239} \rightarrow Pu^{239} + \beta^- \ (2.35\text{d})$$

Pu239 is fissile

Nuclear Waste Problem

By and large, spent nuclear fuel consists of

- Short lived fission byproducts (Strontium 90, Caesium 137) These have lifetimes ~30 years.

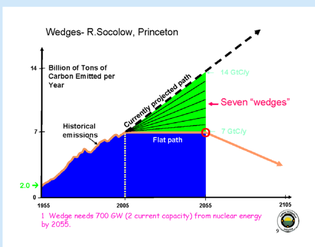
If one stores this waste for ~500 years, very little is left.

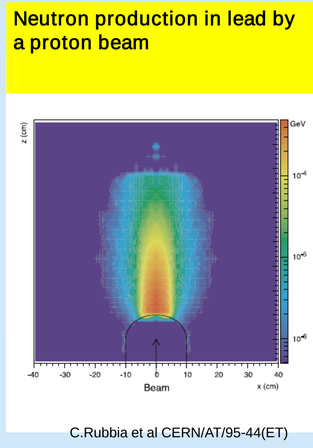
Actinides (Curium248, Neptunium237, Pu 239). These have very long lifetimes and have to be stored away for millions of years for them to decay. Actinides contain stored nuclear energy that can be extracted by feeding them back into an ADS system.

Yucca Mountain waste storage capacity will not be needed and a much smaller temporary facility can be used

Why have we not done this yet?

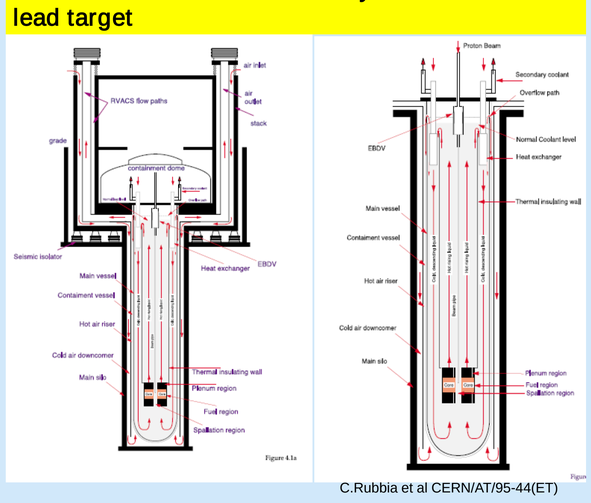
- We need a 10 MegaWatt 1 GeV proton accelerator. This is 10 times more powerful than any machine currently in existence.
- Many solutions have been proposed but none has gone on to the building stage.
- The advent of superconducting radiofrequency technology makes high current accelerators more feasible.





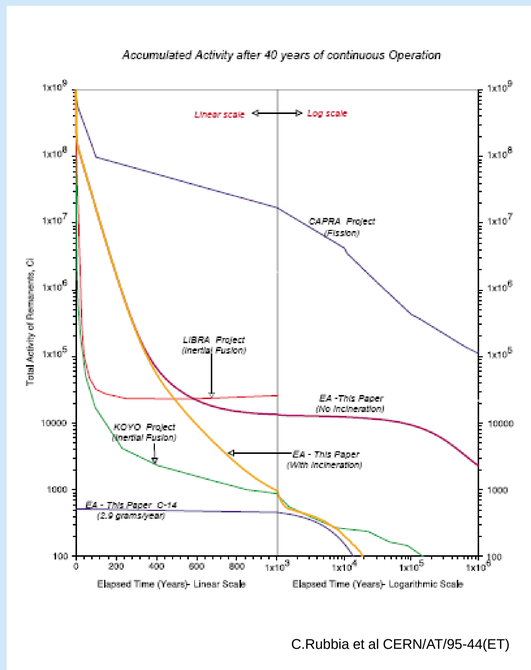
C.Rubbia et al CERN/AT/95-44(ET)

Schematic of an ADS reactor system that uses a lead target



C.Rubbia et al CERN/AT/95-44(ET)

Comparison of waste storage times

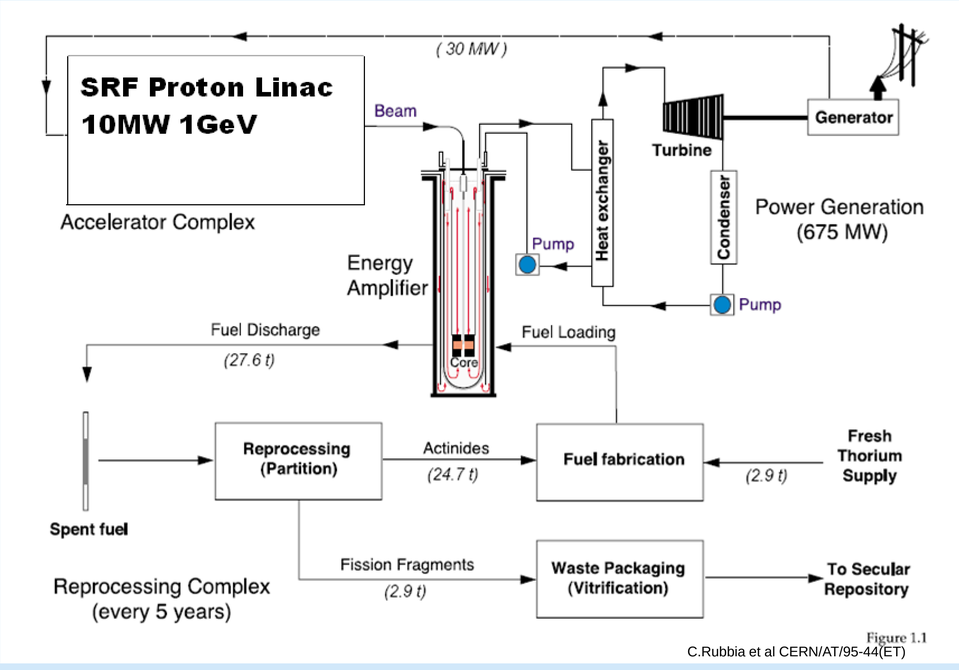


C.Rubbia et al CERN/AT/95-44(ET)

ADS systems-How they work

A beam of protons (>600 MeV) is made to interact with a high atomic number material (spallation target e.g tungsten, lead, lead-bismuth) for producing neutrons. A 1 GeV proton produces ~30 spallation neutrons. If the spallation target is located at the center of the subcritical assembly, it will produce nuclear energy from the fission events caused by the spallation neutrons. This is referred to as an Accelerator Driven System (ADS). These 30 spallation neutrons will produce ~400 fission events in a subcritical core with k=0.97.

This system is a nuclear reactor that can be stopped by turning off the proton beam. ADS has flexibility to use a wide range of fuels including present day nuclear waste.



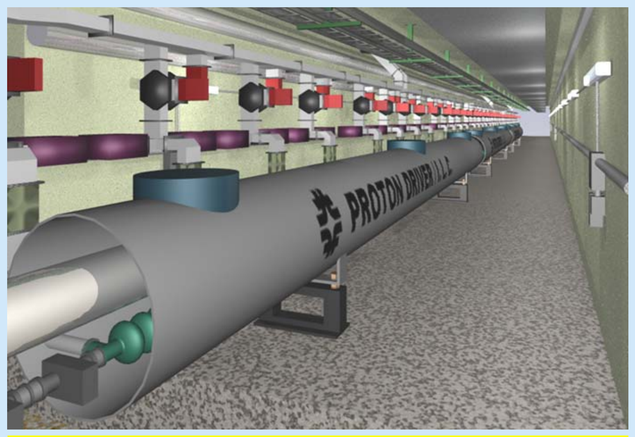
C.Rubbia et al CERN/AT/95-44(ET)

Superconducting radiofrequency cavities (SRF)

Many new accelerators intend to use superconducting rf such as Fermilab's Project-X and the proposed International Linear Collider. The TJNAF accelerator currently employs them to accelerate electrons and the SNS at Oak Ridge accelerates protons to 1 GeV using this technology.

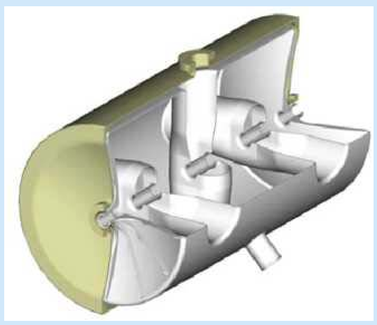
Since the walls of the cavity are superconducting, they permit higher accelerating gradients and higher beam currents with less losses.

A 10 MW 1 GeV proton accelerator that employs Continuous Wave (CW) acceleration is very feasible to build.



Schematic of Project-X Linac in tunnel

Superconducting niobium cavity structures



Conclusions of the Fermilab Workshop AHIPA09

- Significant ADS efforts exist in many countries in Europe, Japan, China and India.
- From the accelerator side, the single outstanding component that has to be demonstrated is a continuous high power (10MW of higher) 1 GeV proton linac.
- The advent of superconducting rf (SRF)technology has made it cheaper and easier to realize such a linac
- Once clean beams of 10mA or higher are established in the low energy (50MeV) section of such a linac, further acceleration to 1 GeV is seen to be straightforward.
- Designs exist of 1999 vintage to build such linacs that can be brought up to date.
- Project-X can be designed in such a way as to make it into an accelerator technology demonstration for ADS, should the U.S decide to make this a national priority.
- Further development is needed in areas such as beam diagnostics and beam halo simulation tools to facilitate building such an accelerator.

- **Old Dominion University, Norfolk, VA 23529, and Thomas Jefferson National Accelerator facility, Newport News, VA 23606,*
- *‡Argonne National Laboratory, Argonne, IL 60439,*
- *†Fermi National Accelerator Lab, PO 500, Batavia IL, 60510,*
- *§IAEA, PO Box 100, 1400 Vienna, Austria*

Fermilab U.S. DEPARTMENT OF ENERGY