The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Continuing the Nuclear Debate

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We have run several articles recently on nuclear power and without fail they have stimulated enthusiastic debate. This is an opportunity to continue that debate. To start us off we have three guest contributions:

> Skip Meier - Nuclear Waste
> Bill Hannahan - We have yet to design the Model T of nuclear power plants
> Charles Barton - Thorium Reserves

Last week the UK's Business Secretary, John Hutton gave one of the most pro-nuclear speeches from a Government minister in which he compared the potential of new nuclear development with the North Sea: *"the most significant opportunity for our energy economy since the exploitation of North Sea oil and gas,"* (Platts). Labour MP Colin Challen responded with a letter in The Guardian:

> John Hutton's latest reflections on nuclear power demonstrate how rapidly British energy policy is regressing to its default mode - dig it up and burn it. At the same time as we are promised the nuclear pipe dream, we are also set to have new coal-powered power stations without carbon capture and storage. This comes at the same time as we have fought for one of the lowest renewables targets in the EU, are languishing third from bottom in current renewables provision out of 27 EU states, and are announcing yet another microgeneration review.
>
> The message Hutton's department seems to want to promulgate in its energy policy is to reassure everybody that no serious change is needed, that we should carry on increasing our demand for energy and that climate change isn't as urgent as some people make out. One can only conclude that the Department for Business, Enterprise and Regulatory Reform is utterly unfit for purpose and should have the title Department for Fiddling While Rome Burns.
> *Colin Challen MP*
> *Lab, Morley & Rothwell*

Nuclear Waste

Skip Meier
70ish Theoretical Physicist with educational studies in the mid 1960's to 1973. Ph.D. work in General Relativity and Quantum Field Theory during the early days of attempted quantization of GR; Thermodynamics of Black Holes. Taught at various colleges throughout the US including the Navajo Nation College at Tsaile AZ. Continuing independent collaboration with others on problems in Gravitational Quantization vs Superstring Pseudo-theories. Presently wandering the canyon country of SE Utah and the Colorado Plateau - in the middle of

Superfund sites from the last uranium boom and within 20 miles of the only US licensed and presently operating Uranium mill. People here are still dying from the last round of careless unconcern for proper handling (and processing) of radioactive materials, including HLRW.

Introduction

There are at least three expressed goals for the increased use of nuclear fission to provide us with useful supplies of electrical energy as fossil fuels go into decline and anthropomorphic global warming becomes manifest and increasingly more threatening.

- To quickly increase the number of nuclear power plants and electrical output from them over the 21st C. allowing coal and natural gas fired plants to be phased out while sustainable and renewable sources of electric energy can be developed and employed. Moving into the 22nd C. and beyond, we can then begin to phase out nuclear power based upon fission energy.
- To develop sufficient electric nuclear power generation as quickly as possible to provide base load requirements into the foreseeable future.
- To quickly adapt nuclear power as the predominant source of energy while moving to a *all electric* society.

It is my position here that disposal of high level radioactive waste (HLRW) is a major concern for all of the above goals and that permanent isolation by deep geologic burial will be necessary - but is not sufficient. I will be using the definitions for “high-level radioactive waste” and "spent nuclear fuel", often referred to as nuclear waste, from the US Nuclear Waste Policy Act (NWPA) found at this site: Link

> (12) The term “high-level radioactive waste” means—
> (A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and
> (B) other highly radioactive material that the Commission, consistent with existing law, determines by rule requires permanent isolation.
> (23) The term "spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

I will not be addressing the issues of the actinic (and transuranic) fractions of the spent fuel but only the fission decay products - the high level radioactive waste as defined in (12) above.

The Physics of Nuclear Fission and Power Generation

For every Kg of fissile fuel that undergoes fission approximately 850-950 gm of highly radioactive waste isotopes are produced.

1 GWe continuous power generation will produce 8.76 GKWhe energy (1 GW Year), consume about 900-1000Kg of fissile fuel and produce about 850-950Kg of high- level radioactive waste (HLRW) per year. This waste is a mixture of isotopes with greatly varying half-lives (decay rates) ranging from fractional seconds to 1My+.

The daughter isotopes will each undergo radioactive decay following the exponential decay function given by A(t) = A(initial)e^ct with c being the individual decay rate of each and related to the half-life by c = -0.693/(half-life in years). However, and this is critical to the understanding of the problem of HLRW, while the fission products undergo their individual decay rates and deplete, more HLRW is being generated at the rate given above - about 850-950 Kg/(GW Year).

The exponential decay function must be reconsidered and modified when the isotope undergoing decay is also being produced. For simplicity, if the rate of production is held constant and is represented by "S", then the amount of that isotope present after a time t is given by the exponential function:

$$A(t) = [A(initial) + S/c] e^{ct} - S/c$$

where c is as before.

Because c is negative -S/c is a positive quantity and e^ct will go to 0 with increasing time, leading to the constant value -S/c for the amount of HLRW accumulated and eventually maintained with a constant yearly production rate.

As stated above, each fractional isotope in the HLRW has a different half-life (HL); each will accumulate to a different limit as time progresses; but a feel may be obtained for what occurs by using an average HL of 50 yrs. (based on the assumption made by many that after 500 years the HLRW is 'harmless'.) Assuming this gives c = -0.014/yr (from c = -.693/HL).

A value of S = 900Kg/yr. and the c above gives an eventual steady state value of:

64 tonne HLRW as the asymptotic limit for each GW Year unit of energy generated and after 500 years (10 HL's) 63 tonne will be present on the planet.

It is certainly true that the 900 Kg produced during the first year will have been reduced to 0.9 Kg. after 500 years but there will be 63 tonne requiring isolation.

Let us consider the single HLRW isotope Cs(137) - which is both a beta and high energy gamma emitter with a HL of 30 yr. and therefore very dangerous. Cs (137) makes up about 3.5% (by mass) of the fissioned nuclei and therefore has a yearly rate of production of about 31.5Kg/yr. for each GW Year unit of energy production.

For Cs(137), c = -0.023 and with S = 31.5 this gives an accumulated steady state value of:

-S/c ~= 1.4 tonne for each GW Year unit of continuous energy production.

Associated Health Risks

High level radioactive waste does not exist in nature (at any measurable level), is partially composed of isotopes of elements, for example cesium, iodine and strontium, that are easily incorporated into the chemical and physiological structures of organisms - they are readily taken up and, if not isolated, will pass up the food chain - in both land and water - from plant/algae to herbivore to carnivore (becoming more concentrated with progression); as they decay within the longer lived higher organisms, cellular and organ damage can occur as well as DNA modification leading to cancer some time later.

Additionally - and very important - some are extremely dangerous without ingestion; merely being in proximity can be very damaging if not fatal. Since 'proximity' depends not only on 'closeness to' and which isotope (and amount thereof) is present but also on time of exposure, it is very difficult to protect against accidental exposure without permanent isolation of the HLRW; this will become exceedingly more difficult as we increase our nuclear power generation output and the total amount of accumulated(-ing) HLRW which include some second (and third) generation isotopes of the original HLRW - for example, Cs(135) with a half-life of 2.5 My.

A review of the radiative characteristics of (some) the HLRW products can be reviewed on the following two links (Wikipedia sites, not complete):

Fission product
Fission product yield

We have yet to design the Model T of nuclear power plants.

Bill Hannahan

Each new technology has a life cycle. It starts with an idea, then a prototype. If the technology involves high energy and/or hazardous materials, the prototype is often the most dangerous example, but there is only one prototype, so its risk to society is low. Risk to the public is greatest when the immature technology is first deployed in large numbers.

We have frozen nuclear power technology at its most dangerous stage of evolution for 30 years, yet it safely generates about 20% of our electricity in the U.S., 80% in France. Next generation plants will have fewer parts and passive safety systems, including the ability to contain a full meltdown.

General Electric ESBWR
Nuclear News on the ESBWR (.pdf)

Westinghouse AP1000

Areva EPR (.pdf)

Today we should be designing fourth generation nuclear plants, building third generation plants, living off the energy of second generation plants and converting our first generation plants into museums. In fact, no two nuclear power plants are exactly alike. We have yet to build the Model T of nuclear power plants.

Imagine that Boeing built airplanes in a swamp, outdoors, far away from any attractive place to live, using minimal tooling and equipment. Workers and equipment would be exposed to rain snow dust heat and insects. Very high salaries would be required to attract workers away from their families to work in harsh conditions. Productivity and quality would be low. The airplanes would be more expensive, less clean, less safe and less reliable than modern factory built planes. That is the way our first generation nuclear plants were built.

We should build facilities to mass produce floating nuclear power plants. They would consist of a canal 600 feet wide and a mile long, enclosed inside a building equipped with high quality lighting, heat, air conditioning, fire protection, communication systems, cranes and tooling, that provide a comfortable safe efficient work environment.

The process begins with a dry dock where a massive steel reinforced concrete barge is constructed. It is floated down the canal for installation of modular equipment. Employees will have safe, permanent, high paying jobs in an attractive coastal location. The application of assembly line techniques will dramatically reduce man-hours, construction time and cost, while improving safety and quality. The completed plants will be towed to coastal or offshore sites, prepared in parallel with plant construction.

The biggest single element in the cost of conventional nuclear plants is the interest on the loan to build the plant, about 1/3 of the total cost, due to the long construction time. Floating plants will be produced initially at the rate of two per year ramping up to about six per year, eliminating most of the interest expense.

A facility to mass produce floating nuclear power plants was actually built, for details see here.

We can make clean safe inexpensive energy available all over the world, have the high paying jobs and control the technology. We can design the plants to be highly resistant to acts of terror and the diversion of nuclear material, insist that plants be subject to international inspection as a condition of sale or lease and sell or lease these plants at a cost that is much lower than traditional construction methods, eliminating the fig leaf of energy production to hide a nuclear weapons program.

Cost

Reducing U.S. emissions now is of minor importance. If we eliminate all of our greenhouse emissions tomorrow, the developing world would gobble up the savings in a relatively short period of time.

The most important goal for the U.S. should be to accelerate the use of our technical capacity to *develop energy technology that is less expensive than fossil fuel* and can be implemented quickly all over the world. People will make the switch quickly and voluntarily, not kicking and screaming.

This is why the U.S. should increase R&D spending for non-fossil energy sources from $3.00 per person per year to $300.00 per person per year, $90 billion per year.

> *The money could be raised simply by adding 2.25 cents to the cost of each kWh.*

We should be pushing every technology as hard as possible and building demo plants of each as it becomes possible.

What are the odds that a submarine reactor on steroids is the best way to produce massive amounts of commercial nuclear power? There are dozens of ways to split uranium and thorium atoms, here are a few examples.

2.25 cents per kWh would raise $18 billion each year from our existing nuclear power plants, more than enough to build at least one demonstration facility to mass produce floating nuclear power plants and several prototype reactors using advanced technology. That leaves $72 billion per year for non nuclear energy R&D.

Mandating the widespread use of expensive energy systems has resulted in the highest electricity prices in the world, Denmark, 41 cents per kWh, Germany, 30 cents per kWh (Electricity prices for EU households and industrial (.pdf)) yet they still get most of their electricity from fossil fuel.

We pay 9.5 cents per kWh in the U.S... A year's supply of electricity costs the average American $1,260. Mandating expensive energy systems could easily double that figure. Technology mandates are far more expensive than the cost of developing better technology.

Letting a bunch of gray haired law school graduates in Washington DC try to cherry pick energy technology is a formula for disaster.

France is 80% nuclear, most of the rest is hydro, and they pay 19 cents per kWh. France runs its nuclear power industry like the U.S. runs the post office, and they are building windmills now to show more renewable energy, so their cost will likely rise in coming years.

Our nuclear power plants have been paid off for a long time and they help keep prices down. The operation and maintenance cost for U.S. nuclear plants in 2006 was 2.0 cents per kWh (link) including the fuel assembly cost of 0.5 cents per kWh, of which the uranium cost was 0.19 cents per kWh.

Expensive energy systems will not solve the world's energy problem because most people cannot afford them.

If we spend 2.25 cents per kWh on R&D for a decade or so we can solve the energy problem and save over $1,000 per person per year for centuries. Accelerating the development of low cost, clean, safe energy systems is the greatest and cheapest gift we can provide to future generations.

For more details go to: Bill Hannahan's essay on energy.
Download the PDF and spreadsheet (mid page).

Thorium Reserves

Charles Barton
Charles Barton grew up in Oak Ridge, where his father was a reactor chemist. Barton learned about Liquid Fluoride Thorium Reactors from his father, who spent nearly 20 years researching them. A retired counselor, his blog, Nuclear Green focuses on the history of nuclear research, and on the potential role of thorium cycle reactors in providing the world's energy needs.

In 1962 a team of Geologists from Rice University in Houston, Texas, took a few months to explorer the Conway Granites of Vermont. At the time Rice Geologists were usually involved in a search for oil, but these geologists were under contract from Oak Ridge National Laboratory to look for Thorium. ORNL Scientist had the crazy idea that they could build a thorium fuel cycle reactor that could produce a billion watts of electrical power for a year from less than a ton of thorium.

The Rice Geologists J. A. S. Adams, M.-C. Kline, K. A. Richardson, and J. J. W. Rodgers reported:

> The costs of extracting the uranium and thorium from the Conway granite are estimated by workers at the Oak Ridge National Laboratory to be less than $100/pound, or at most five to ten times the present costs of nuclear raw materials. This source of nuclear fuels, therefore, is currently uneconomic compared to the sources now being utilized. In terms of total energy content, however, the Conway granite represents an energy resource several orders of magnitude larger than the lower cost material. In the long-term future, when supplies of cheap uranium and thorium may start to be exhausted, sources such as the Conway granite may become increasingly important and necessary.

They concluded:

> Thus the importance of the present work on the Conway granite lies in the indication that tens of millions of tons of thorium are available when the need for vast amounts of higher-cost nuclear fuel becomes pressing. These amounts may be compared to the few hundreds of thousands of tons of previously estimated thorium reserves. It is reassuring to know that the long-term future of nuclear power is not limited by the supply or by a prohibitively high cost of fuel. Furthermore, the Conway granite may become even more important considering the likelihood that improved extraction techniques may make the thorium available at costs well below the $100/pound estimated in preliminary laboratory experiments. It is also possible that larger amounts of lower-cost thorium might be realized by locating high-grade ore reserves such as the Lemhi Pass, Idaho, area may prove to be, or by finding a large granitic batholith more economic than the Conway."
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> ...
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> "Finally, it should be noted that the statistical and exploration techniques developed in the present work and described above, particularly the portable gamma-ray spectrometer, may make it possible to explore for thorium and develop reserves far

> more cheaply and rapidly than was the case for uranium.
>
> Source (.pdf)

Last year the a rumor began to circulate on the Internet of a remarkable geological find at Lemhi Pass in Idaho. Recently the USGS has estimated the United States Thorium reserve at 160,000 tons, but the story that was circulating claimed an assured reserve at Lemhi Pass alone of 600,000 tons. Thorium is a heavy metal. Like Uranium 238, Thorium 232 is fertile. Thorium absorbs neutrons, in reactors and other neutron rich environments. The neutron triggers a transformation process that converts Th233 into U233. U233 is fissionable like U235 and Pu239.

Thorium Energy, Inc., the major holder of the Lemhi Pass thorium vein, recently posted on the Internet a report on its Lemhi Pass finding:

> Thorium Energy, Inc.™ owns the proprietary mineral rights to the largest claim in this region, representing what is believed to be one of the single largest privately owned Thorium reserves in the world.
>
> ...
>
> The Company's reserves consist of 68 separate resource claims, each consisting of approximately 20 Acres, located in the Lemhi Pass Region, which is situated along the border between Idaho and Montana. Included in the Company's claims are significant mining veins, which contain 600,000 tons of proven thorium oxide reserves. Various estimates indicate additional probable reserves of as much as 1.8 million tons or more of thorium oxide contained within these claims. The Company's claims also include significant deposits of rare earth metals.
>
> ...
>
> Metallurgy tests conducted in the region estimate that the average mine run grade is approximately 5% or more of thorium oxide (ThO 2). In fact, vein deposits of thorite (ThSiO 4), such as those that occur in the area of the Lemhi Pass, present the highest grade thorium, mineral, and are believed to contain approximately 25 to 63 percent thorium oxide (ThO 2) per ton of raw ore. Thus one ton of thorium ore could potentially yield as much as 500-1,200 lbs. of high grade thorium oxide (ThO 2), as compared with less than one percent of raw Uranium ore that is typically utilizable. The deployment of Lemhi Pass Thorium represents a more economically feasible source of nuclear grade ore than Uranium deposits.
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> Source (.pdf)

Why is this thorium reserve just now being discovered? An Australian Government, Geoscience Australia report states:

"Exploration for thorium to date has been minimal and there are no comprehensive records of resources, mainly because of a lack of large-scale commercial demand."

What is true of Australia is also true of the United States, and indeed the rest of the world.

Research has demonstrated that it is possible to design reactors that will convert thorium 232 to U233 very efficiently. 800 kg of thorium 232, under a ton, converted into U233 can produce a billion watts of electricity for a year.

See Liquid Fluoride Reactor (Wikipedia)

The 600,000 proven tons of thorium at Lemhi Pass represent enough energy to power the United States for as much as 400 years. 1.8 million tons of thorium contains enough energy to power the United States for well over 1000 years. The tens of millions of tons of thorium that Rice University Geologists reported in 1962 finding in the Conway granites of Vermont could last the United States for a very long time.