THE TRUE VALUE OF SPENT NUCLEAR FUEL

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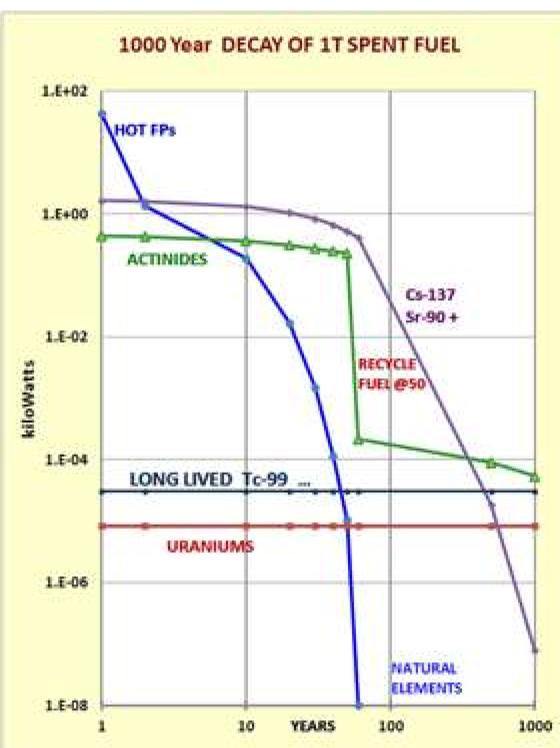
ABSTRACT

Analysis of 50 year old spent nuclear fuel has shown all its contents to be very valuable. With recycling, less than 0.2% needs burial for less than 1000 years. There is no need for huge Geological Disposal Facilities. Molten salt Thorium reactors will produce 0.01% of the actinides from any light water reactor, breed their own fuel, allow online reprocessing, and cannot burn or melt down. Ten Hybrid Fusion-Fission reactors could consume all the high actinides from existing spent fuel stockpiles by 2100. Hybrids can also run safe sub-critical fission. China will lead the world in innovative nuclear energy by 2030. A strong nuclear future will secure thousands of careers in engineering. Two UK reactor projects could restore the UK position in nuclear science and engineering.

SPENT FUEL

The common understanding of spent fuel is that it is waste to be buried for a million years, but this is not remotely true. Properly recycled, no more than 0.2 % needs burial for less than 1000 years. A 1000 MW (GWe) reactor consumes the equivalent of 1 tonne of Uranium-235 per year, or about 30 milligrams a second. At reactor shutdown, fission and transmutations by neutrons stop and there is only decay. An analysis of 1 tonne of 50yr old US spent fuel from a Light Water Reactor (LWR) found enormously valuable Uraniums (955kg) and Plutonium reactor fuel (8kg) and Fission Product (FP) isotopes (35 kg) of precious metals, rare earths, and faintly radioactive elements with many industrial uses, and slightly activated Zircalloy fuel cladding (Sayre, 2006).



The chart shows Sayre's data rolled back by 50 years and forward to 1000 years. In 10 half lives, each unstable isotope decays by $1/2^{10} = 1/1024$ or a billion times in 30 $T_{1/2}$. The fastest decaying Hot FP's, responsible for possible meltdowns, are not in the 50yr fuel and have been modelled here from other data (US-NRC, 2008). They decay to join the other natural isotopes produced, the most valuable being Rubidium, Ruthenium, Silver, Rhodium, Palladium, Xenon and Neodymium.

The troublesome isotopes are 2.3 kg. Of Cesium-137 and Strontium-90 with $T_{1/2}$~ 30yr whose activity drops to that of natural Uranium at 600 yrs. Only these need to be buried for any length of time.

The next most active group are the Plutoniums and the minor Actinides - Neptunium, Americium and Curium. Solid fuel may be recycled after 10 years. The recovered Uraniums and Actinides return to reactors. Recycling leaves 1:1000 parts behind in the processing liquors, which drop to the Uranium activity by 1000 yrs as shown.

Finally, there is a group of very weakly radioactive FP's like Technetium-99 which have industrial uses. Indium-115 has $T_{1/2}$~ 30,000 times the age of the universe and is used in touch screens. The total value of the FP's from the spent fuel from a GWe plant is about £10M. Fresh fuel from mined Uranium costs about £1.5M/t.

The recovered Uranium may be transmuted to Plutonium-239 in breeder reactors and would then be worth ~£30Bn in electricity sales. The recovered Plutonium is re-used as MOX in France for a similar electricity value per tonne. The Actinides are best used in advanced reactors.

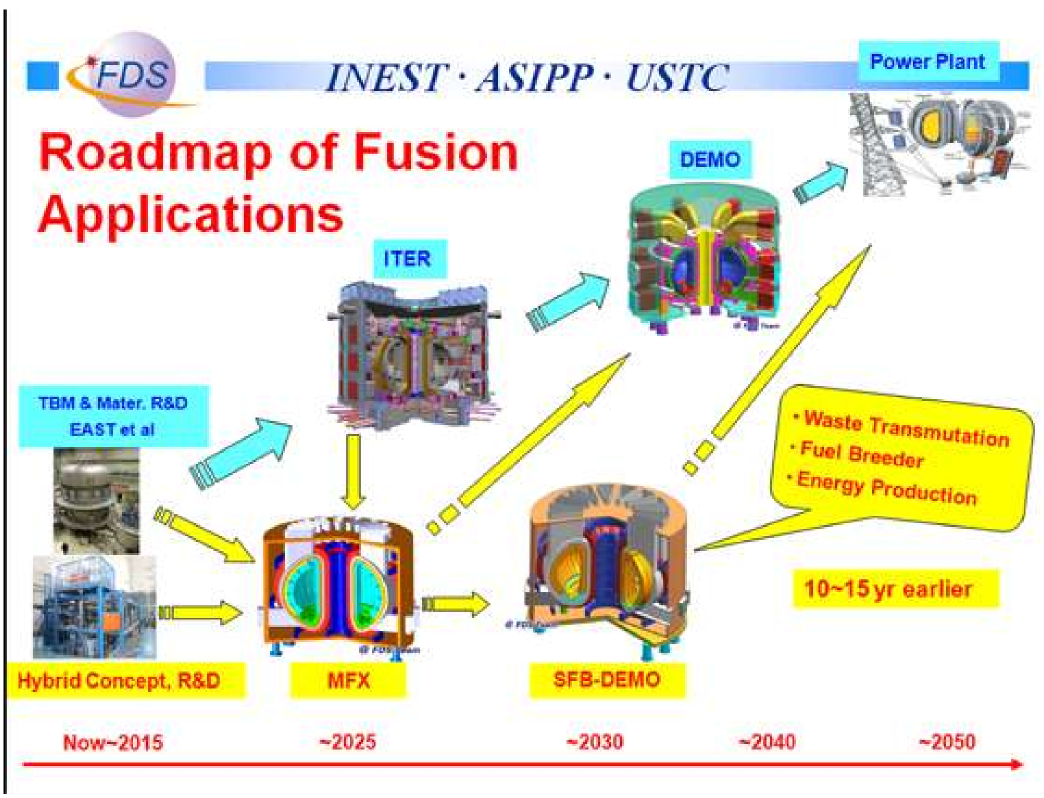
It is clear that burial of spent fuel in a Geological Disposal Facility (GDF) is a waste of very valuable assets. The first waste would go to a UK GDF from 2050. The world actually needs several thousand reactors by 2050. That will put pressure on Uranium supplies and make recycling imperative. For the wrong political reasons, the nuclear industry has had a free ride without recycling and built up an 8,000 LWR reactor-year stockpile of spent fuel. Several proposals and prototypes (Moir, 2005) for more advanced reactors should be accelerated now.

MOLTEN SALT THORIUM REACTORS

The Molten Salt Thorium Reactor has two major advantages: (a) It produces no Plutonium or minor Actinides. (b) The circulating molten Uranium-233 Fluoride reactor salt is readily recycled by an attached, robotic plant. The Cesium and Strontium can be removed to reduce the salt radioactivity. Thus, the decay curves for Actinides and Cs-Sr are eliminated. These Thorium reactors are one of the world's safest designs which cannot burn or melt down and breed their own fuel. They could supply a good portion of the world's energy needs by mid-century. A £100M prototype could be built in 10-15 years. The recently founded Weinberg Foundation (www.the-Weinberg-Foundation.org) seeks to promote MSTRs in the UK.

HYBRID FUSION-FISSION REACTORS

Fusion will soon provide spectacular ways of burning minor Actinide fuels for electricity, breeding fresh Plutonium from Depleted Uranium or U-233 from Thorium-232, and much safer sub-critical Uranium power reactors in thermal or fast neutron modes. These Fusion-Fission Hybrid Reactors use the flood of hot neutrons from a small fusion core of 100-200MW to drive processes in surrounding blankets of target fuels. The Hybrids still produce a GWe from the blankets.



China is building three fission reactors per year and is also set to become the leader in fusion development. The diagram by their Fusion Driven Systems team (www.fds.org.cn) shows the high track to fusion electricity, with input from their EAST Superconducting Tokamak to the 500MW International ITER project in France. Their DEMO commercial reactor follows and Power Plant deployment should start from 2050. The low track adds a comprehensive set of test rigs for blanket engineering and chemistry leading to a Multi-Functional test reactor (MFX). An FDS Hybrid subcritical system has been designed as a Spent Fuel Burner (SFB). The burners, breeders, and safe sub-critical reactors could all be there 10-15 years before the high road Power Plant.

This marriage of fusion and fission has extraordinary benefits as found in many British, Brazilian, Chinese, Russian and US design studies (Galvao,2008). A burner can consume the annual output of minor Actinides from 25 reactors. Recycling and 10 Hybrid Actinide Burners could eliminate the current stockpiles of spent LWR fuel by 2100. A Hybrid breeder can produce fuel for 4 reactors, far exceeding the capability of any stand-alone Fast Reactor. The UK has sufficient Depleted Uranium in stock to run an all electric Britain for 500 years.

The first commercial entry in this race is being made by Tokamak Solutions UK Ltd. at Culham, Oxfordshire (www.tokamaksolutions.co.uk). At fusion powers below 50 MW it is possible to use industrial upgrades of existing technologies and materials to build a Spherical Tokamak system as a powerful fusion neutron source. Such a £200M prototype core could be built in 10-15 years.

CONCLUSION

Nuclear energy needs the best young engineers and scientists to build new systems which will be far safer, cleaner, and flexible enough for millennia. The first such commercial systems are within the career span of current graduates. The development costs are a minute fraction of that proposed for geological disposal. The UK must become a player again in such high technologies.

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