Fusion Breeding, from the ugly Duckling to the beautiful swan

Wallace Manheimer

Wallace Manheimer, Fusion: It's time to color outside the lines, Open Journal of Applied Sciences, March 2024, https://www.scirp.org/journal/paperinformation?paperid=132258

Wallace Manheimer, Fusion breeding and pure fusion development, perceptions and misperceptions, International Journal of Engineering, Applied Science and Technology, 2022, Volume 7, Issue 7, p 125-154, https://www.ijeast.com/papers/125-154,%20Tesma0707.pdf

Statements about the Ugly Duckling

*‘Hybrid fusion combines the worst aspects of fusion with the worst aspects of fission!.’

*‘You present fusion breeding as a producer of fuel for nuclear reactors. But fuel supply is the **ONE** problem fission **DOES NOT** have!’

*“Forget fusion breeding, there is plenty of uranium in the world’s oceans. Uranium from it will cost only $200 per pound!”

*All of these statements are false!

*Let’s look at them one by one.

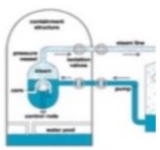
‘Hybrid fusion combines the worst aspects of fusion with the worst aspects of fission!.’

*In a sense, this is true, but in a larger sense false. It considers only the wrong aspects of hybrid fusion, namely:

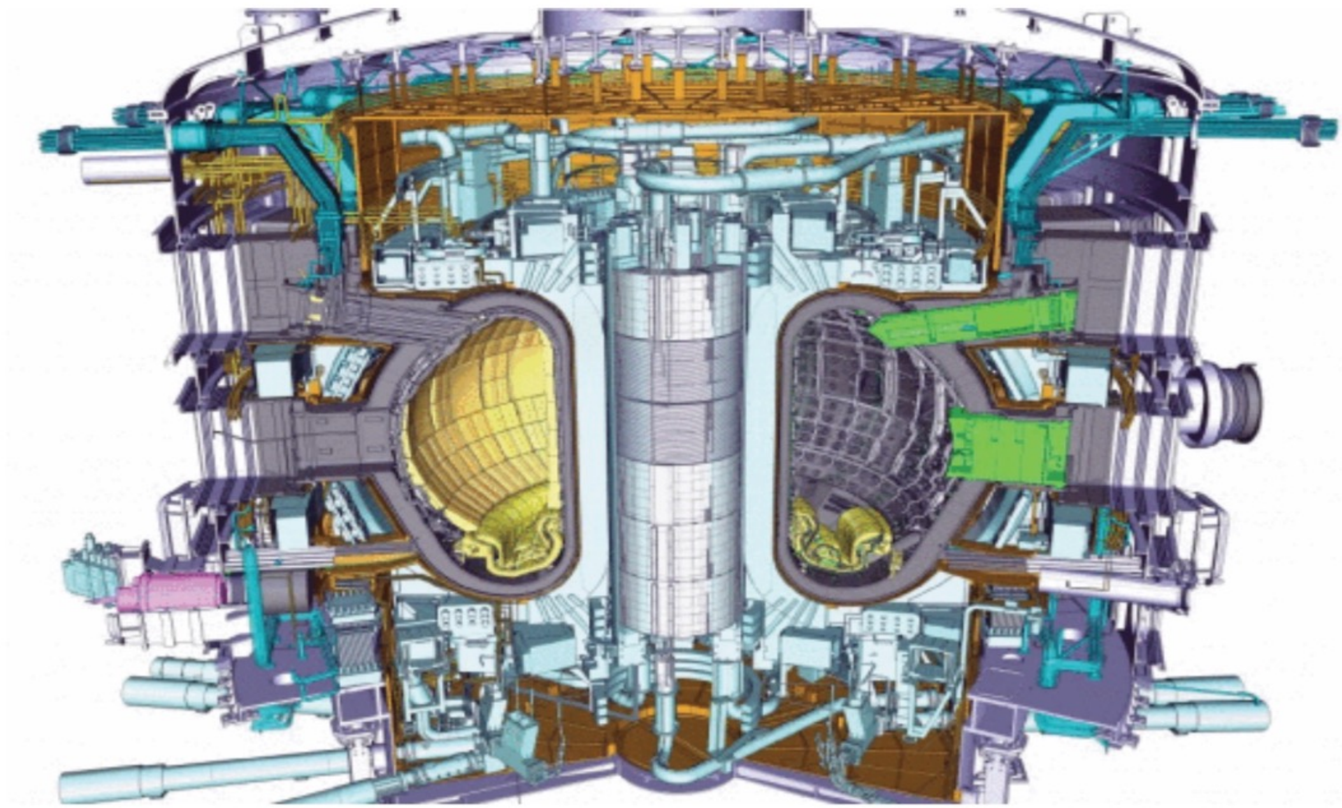
*Using fusion neutrons as an external knob to control the fission rate and allowing the fission reactor to be subcritical. But we have been building critical reactors, safely and economically for decades, no need for an external control.

Also fusion reactors, whether ITER, W7X, NIF, are **BIG, REALLY BIG!**

Here is what the light water reactor with that one extra control knob would look like:



LWR



ITER (now the control knob)

What about surrounding the fusion reactor with a blanket containing uranium?

- Every 14 MeV fusion neutron, which reacts with the uranium produces 200 MeV.
- Obviously at some point the fission reactor will take over and destroy the blanket and the reactor.
- This is obviously **NOT** the version of hybrid fusion anyone would advocate.

You present fusion breeding as a producer of fuel for nuclear reactors. But fuel supply is the **ONE** problem fission **DOES NOT** have!'

George Stanford, one of the main developers of the IFR:
Fissile material will be at a premium in 4 or 5 decades.....I think the role for fusion is the one you propose, namely as a breeder of fissile material if the time comes when the maximum IFR breeding rate is insufficient to meet demand.

Dan Meneley: Former head of Canadian nuclear program: I've nearly finished prepping my talk for the CNS on June 13th (2006) -- from what I can see now, we will need A LOT of fissile isotopes if we want to fill in the petroleum-energy deficit that is coming upon us. Breeders cannot do it -- your competition will be enrichment of expensive uranium, electro-breeding. Good luck.

With fracking and new giant gas fields recently discovered, these petroleum deficits are still coming on us, just later than Dan thought.

“Forget fusion breeding, there is plenty of uranium in the world’s oceans. Uranium from it will cost only $200 per pound!”

Various absorbents have been used and researched.   Only one ocean extraction program has been done in a Japanese ocean current about 35 years ago and never repeated. In a year it produced 10 grams of 235U, about half 1/4 teaspoon full, in a project costing millions of dollars.

The world now uses about 700 tons of 235U yearly. How can anybody reliably extrapolate from 10 grams for ($$$ millions in a test tube), to 700 tons (giant factories and fleets of ships) for $200 per pound. It makes no sense!

Uranium from seas may or may not have a future, but it is not worth putting all our eggs in that basket. Most likely it will never be viable or economic.

Statements about the beautiful swan

The worst manifestation of ‘hybrid fusion’ is horrible, but the best, ’fusion breeding’ is beautiful.

Fusion breeding may well save ITER’s ---.

The high energy of the fusion neutron allows many possibilities for breeding tritium and ^{233}U.

A tokamak can never win a 1 to 1 competition with an LWR.

A fusion breeder can easily win a competition with a fission breeder.

A fusion breeder can be the lynchpin of an energy infrastructure which is sustainable, clean, and has little of no proliferation threat.

The worst manifestation of ‘hybrid fusion’ is horrible, but the best, ’fusion breeding’ is beautiful.

The way to do it is with a flowing liquid blanket which has some thorium dissolved in it. This way each fusion neutron can make a 233U, which has 10 times the potential energy of the neutron.

The fluid flows to a chemical plant, where the tritium and ^{233}U are removed. The ^{233}U is then diluted to ~ 4% as is typical to for fuel for an LWR.

Fusion breeding may well save ITER's ---.

ITER hopes to show 500 MW of neutron power with 50 MW of beam or microwave power driving it, i.e. Q=10.

Electricity is generally produced with an efficiency of 1/3, meaning ~ 170 MW will go to running ITER.

But the beams and microwaves driving it, are also produced with ~ a 1/3 efficiency, meaning they need 150MW.

There is nothing left for the grid!

ITER understands this. Its web site says that ITER is only a first step to a DEMO which has higher power, higher Q, is cheaper, and smaller.

Who knows how many $10's of billions this will take, how long it will take and if it is possible at all.

If ITER is just run as a fissile fuel factory, it can produce this fuel safely, sustainably, cleanly, and economically. Each 14 MeV produces >200MeV of nuclear fuel for use in LWR's.

There would be no need for the DEMO!

ITER would itself be an end product!

The high energy of the fusion neutron allows many possibilities for breeding tritium and ^{233}U.

n + 7Li → T + He + n (−2.47 MeV)

In theory at least, a single 14 MeV neutrons can produce as many as about 5 tritons

n + Be → 2He + 2n (−2.7 MeV)

In theory at least, a single 14 MeV neutron can produce as many as about 5 233U Nuclei

Many careful calculation need to be done

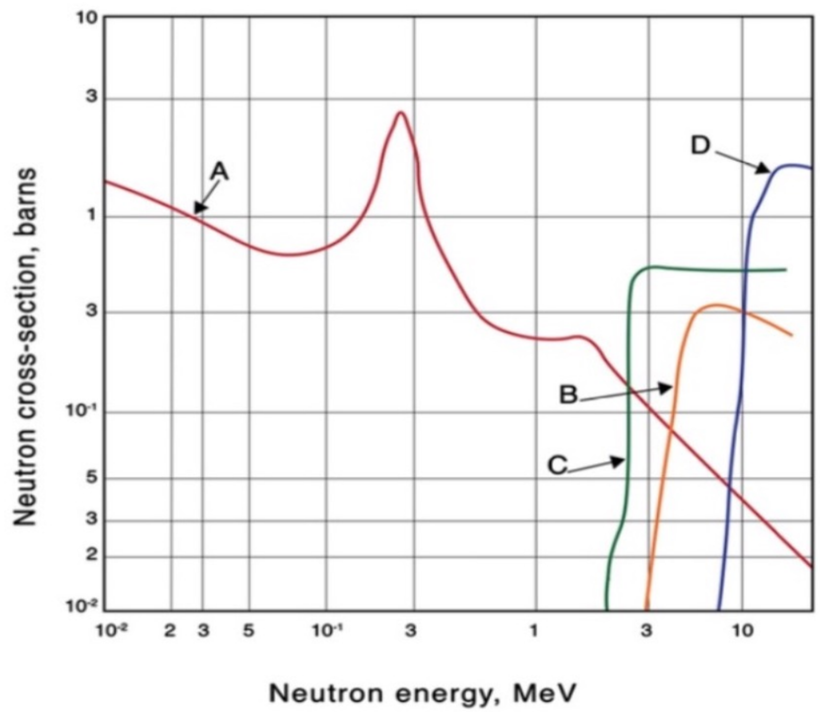


Figure 23. Collision cross sections for several of the most important reactions for fusion breeding. The red curve (A) is the cross section for tritium production from ^6Li; the orange curve (B) for tritium production from ^7Li, a process that preserves the neutron; the green curve (C) the cross section for a neutron spallation collision with ^9Be, and the blue curve (D), neutron spallation from Pb.

A tokamak can never win a 1 to 1 competition with an LWR.

Just look at the image to the left

A fusion breeder can easily win a competition with a fission breeder.

It takes 2 fission breeders at maximum breeding rate to fuel one thermal reactor of = power; one fusion breeder can fuel 5 or 10!

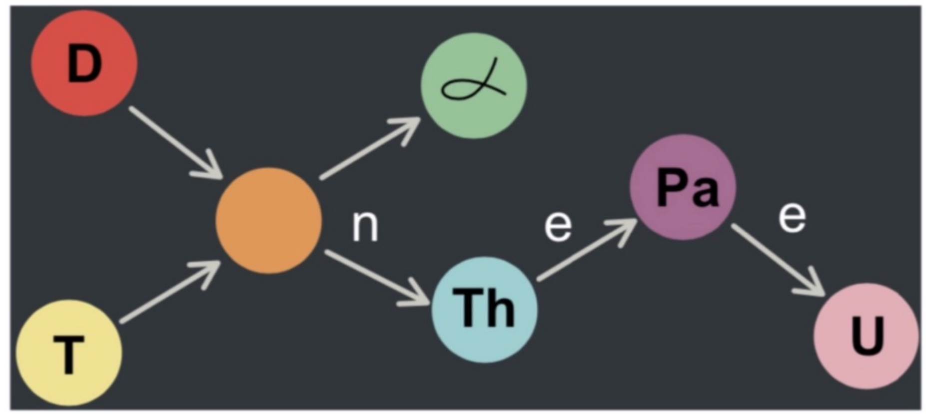
Why is this? Because neutrons are our friends, not our enemies!

A fast neutron breeder produces ~ 3 neutrons per reaction. One is needed to continue the chain reaction, one to replace the burned neutron, and one is left over for other purposes. Half is lost and half produces an additional fissile neutron.

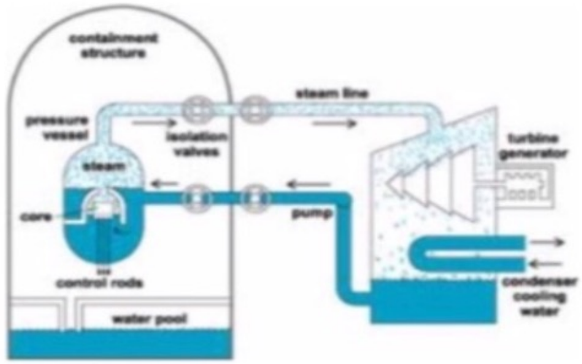
In a fusion reaction, a single 14 MeV neutron is produced. Because of its high energy, it can produce 1-2 more by spallation. Also, the ^{7}Li tritium breeding preserves the neutron. Say 1.1 is needed to breed the tritium, leaving say 1.4. 0.9 are lost and half produces a fissile neutron.

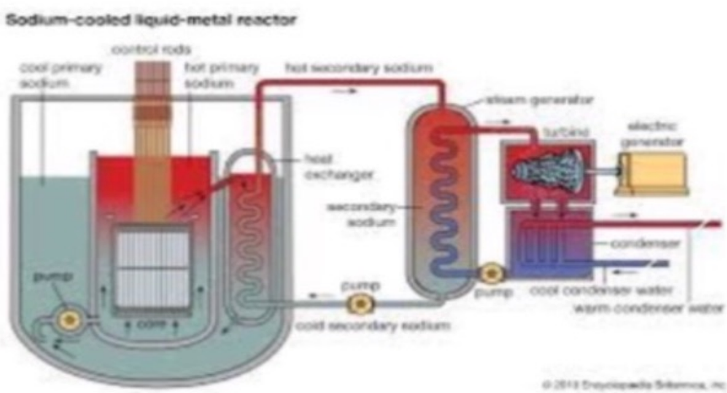
But the fission reaction is 200 MeV, while the fusion reaction is only 14! Each reaction produces ~0.5 fissile atoms, so fusion is at least an order of magnitude more prolific as a breeder than is fission!

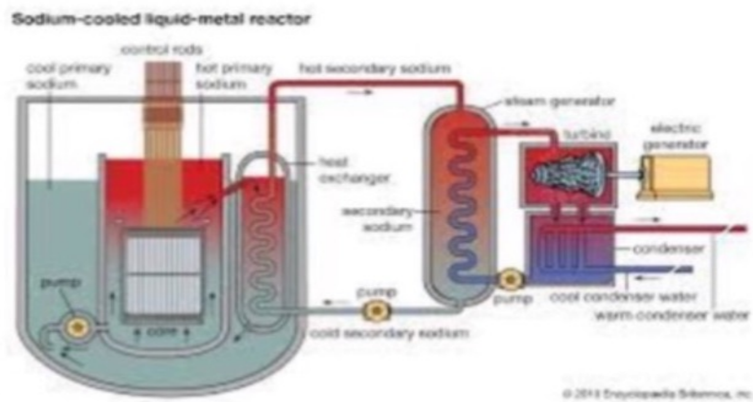
Fission is energy rich and neutron poor; fusion is neutron rich and energy poor. A perfect match!

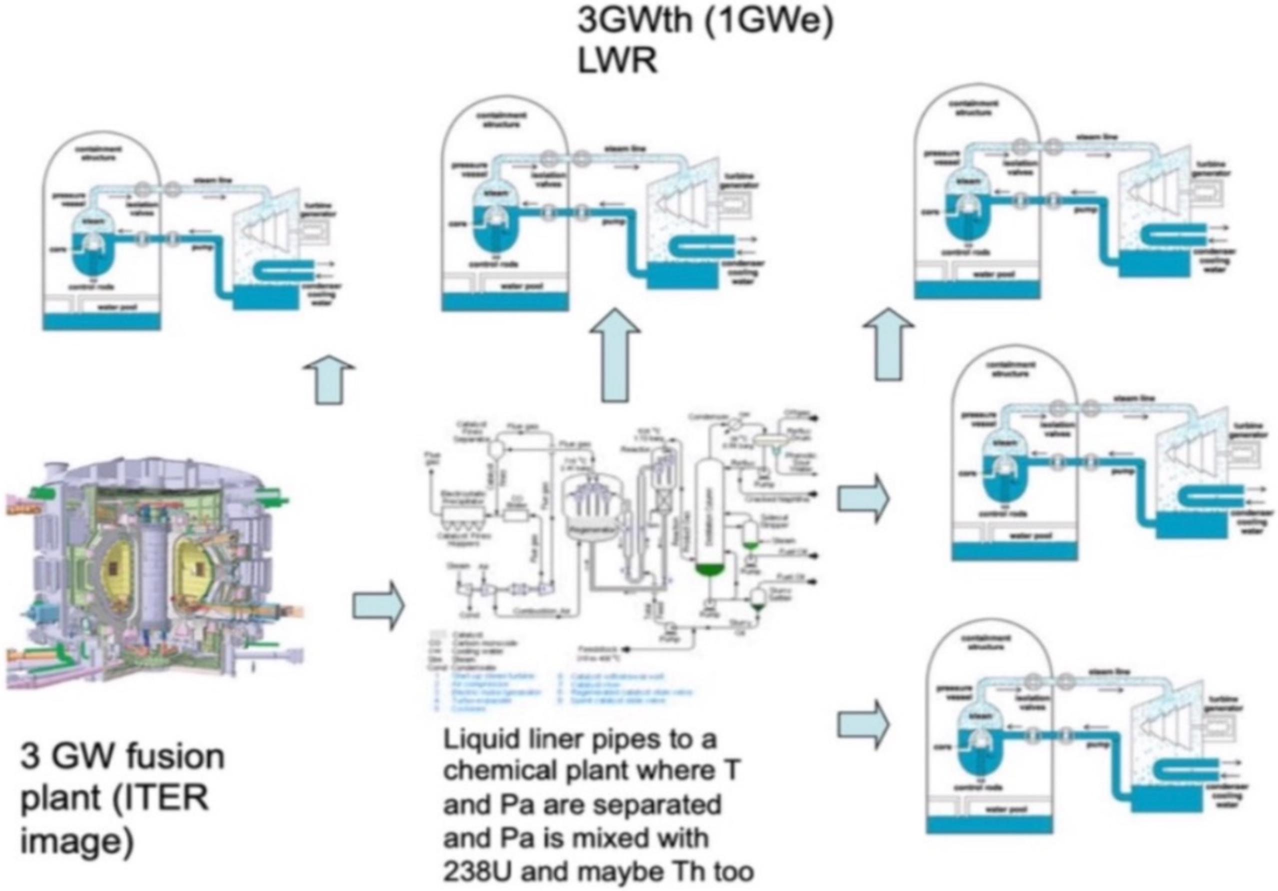


The fusion breeding reeactions


containment structure
steam line
pressure vessel
isolation valves
turbine generator
steam
core
pump
control rods
condenser cooling water
water pool


Sodium-cooled liquid-metal reactor
control rods
cool primary sodium
hot primary sodium
hot secondary sodium
steam generator
turbine
electric generator
heat exchanger
secondary sodium
condenser
pump
pump
pump
cool condenser water
warm condenser water
core
cold secondary sodium


Sodium-cooled liquid-metal reactor
control rods
cool primary sodium
hot primary sodium
hot secondary sodium
steam generator
turbine
electric generator
heat exchanger
secondary sodium
condenser
pump
pump
pump
cool condenser water
warm condenser water
core
cold secondary sodium



Only fusion breeders can fuel many LWR's which have run out of fuel.

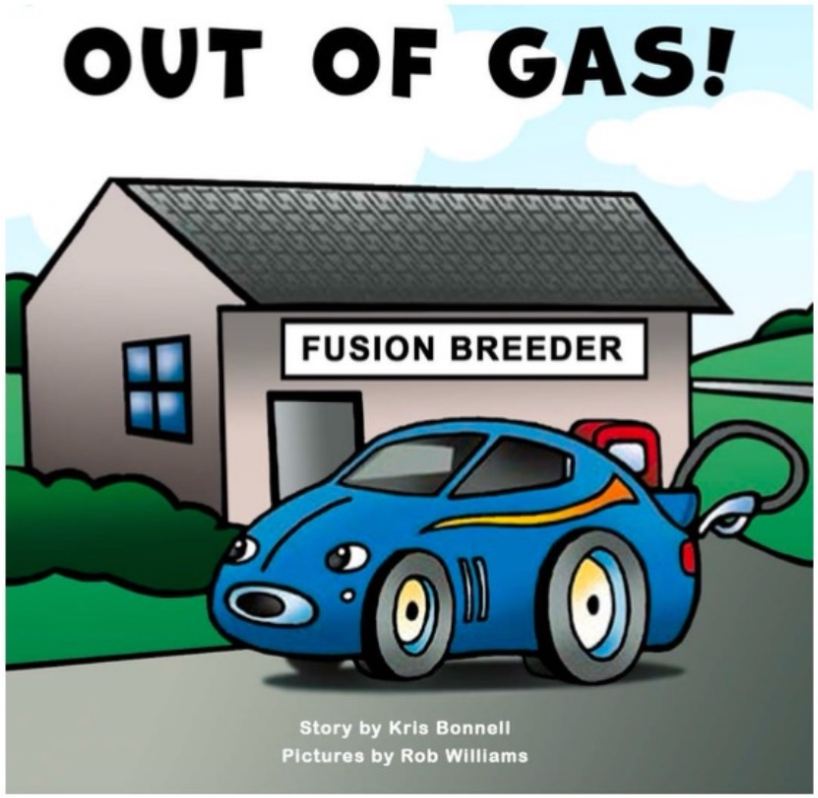


Figure 6. Of all breeding options, only fusion breeding can "refuel" thermal reactors once they "run out of gas" and are stranded.

A fusion breeder can be the lynchpin of an energy infrastructure which can be clean, sustainable and have little if any proliferation risk

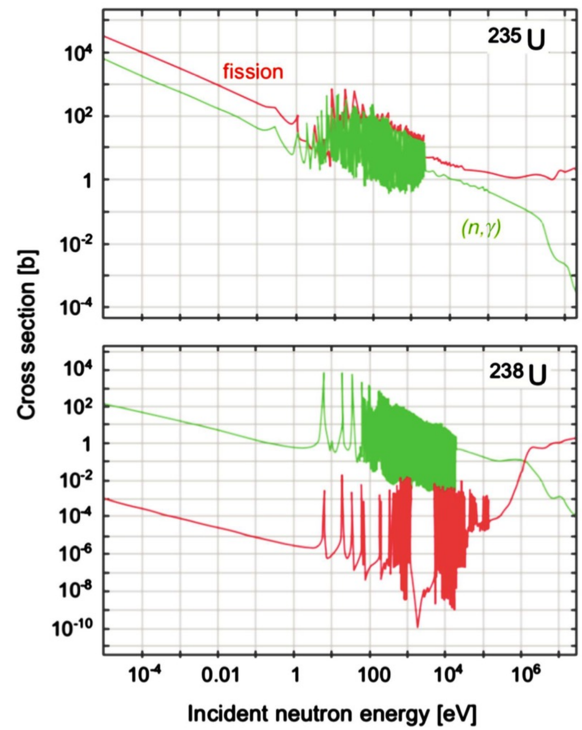
An LWR, after a year discharges about 20% of the fuel load in actinides other than uranium

An integral fast reactor (IFR) can burn any actinide, fissile or fertile about equally.

This indicates that an energy infrastructure could contain one fusion breeder to fuel 5 LWR's, and one IFR to burn the actinide discharges.

This could be the element of a sustainable, environmentally sound power structure which has little proliferation risk.

Fissile material is diluted as it is produced, and the actinide discharged is immediately burned in an IFR



At ~ 2 MeV, all fission cross sections are about the same.

The energy park

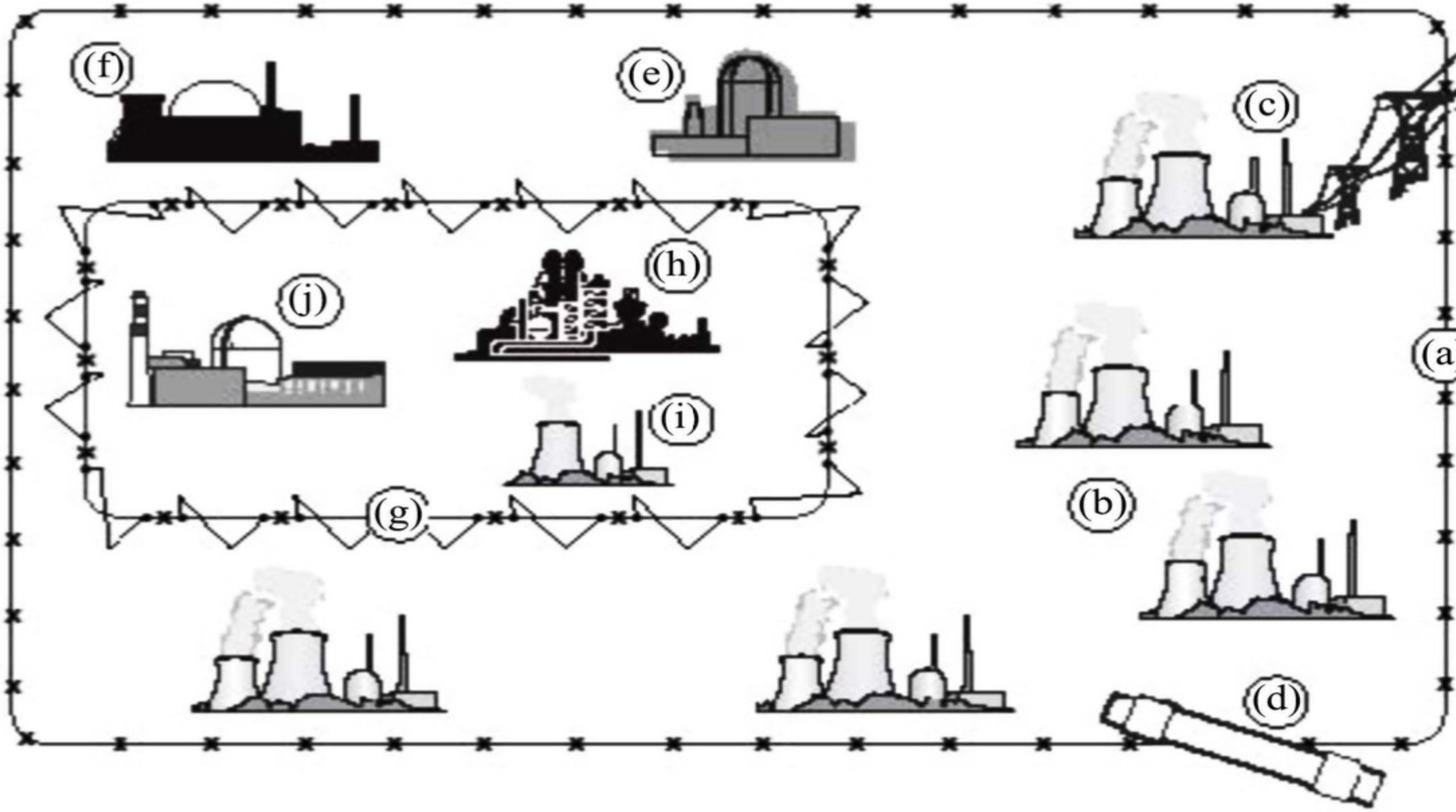


Figure 28. The energy park: (a) low security fence; (b) 5 thermal 1 GWe nuclear reactors, LWRs or more advanced reactors; (c) output electricity; (d) manufactured fuel pipeline, (e) cooling pool for storage of highly radioactive fission products for 300 - 500 years necessary for them to become inert. This is a time human society can reasonably plan for, unlike the ~ half million years the plutonium "waste" would continue to be a threat to humankind. A sustainable energy infrastructure should not create a plutonium mine; (f) liquid or gaseous fuel factory; (g) high security fence, everything with proliferation risk, during the short time before it is diluted or burned, is behind this high security fence; (h) separation plant. This separates the material discharged from the reactors (b) into fission products and transuranic elements. Fission products which have commercial value would be separated out and sold, the rest go to storage (e), transuranic elements go to (i); (i) the 1 GWe integral fast reactor (IFR) or other fast neutron reactor where actinides like plutonium are burned; (j) the fusion breeder, producing 1 GWe itself and also producing the fuel (ultimately enriched to ~4% ^{233}U in ^{238}U) for the 5 thermal nuclear reactors for a total of 7 GWe produced in the energy park.

Publications

First paper:

W. Manheimer, Back to the future, the historical, scientific, naval and environmental case for fission fusion. Fusion Technol. **36**, 1 (1999)

CDR's first discussed

W. Manheimer, Hybrid fusion: The only Viable Development Path for Tokamaks? J. Fusion Energ. **28**(1), 60 (2009)

Open access papers in major journals:

Wallace Manheimer, 2014, ''*Fusion breeding for mid-century sustainable power,*'' J. Fusion Energy, , 33, 199–234,. [Online]. Available: https://link.springer.com/article/10.1007/s10894-014-9690-9

Wallace Manheimer 2020, *Fusion breeding for mid-century, sustainable carbon free power, Helioyon (Cell network)* #1 6 e04923 https://www.sciencedirect.com/science/article/pii/S2405844020317667#!

Wallace Manheimer, 2018, *Midcentury carbon free sustainable energy development based on fusion breeding*, IEEE Access, December, Vol 6, issue 1, p 64954-64969, https://ieeexplore.ieee.org/document/8502757

Wallace Manheimer, 2020, *Fusion breeding as an approach to sustainable energy*. Discover Sustainability 1**,** #2. https://doi.org/10.1007/s43621-020- 00004-9

Wallace Manheimer, *Fusion breeding and pure fusion development perceptions and misperceptions*, International Journal of Engineering, Applied Science and Technology, 2022, Volume 7, Issue 7, p 125-154, https://www.ijeast.com/papers/125-154,%20Tesma0707.pdf

Wallace Manheimer, *Fusion: It's time to color outside the lines,* Open Journal of Applied Sciences, March 2024, https://www.scirp.org/journal/paperinformation?paperid=132258