Liquid Blankets & Fusion-Fission Hybrids

Fusion-Fission Research Workshop

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Abstract

This talk is a short overview/review. A variety of fusion reactor concepts have called out the advantages of using a liquid first wall. Thick liquid walls can absorb neutrons, change plasma/wall interactions through beneficial gettering, mitigate damage from pulsed loading, and have no neutron damage issues (assuming that solid structural elements are sufficiently shielded). Typically molten salts (Fluorine-Lithium-Beryllium, or FLIBE) or Lead-Lithium are envisioned. It is also likely that early fusion reactors may only support limited gains (fusion gain Q ~ 2-20), but still be required to breed their own tritium. The question is, how could such systems be improved with fission added to the mix? Remarkably, without any new engineering systems close to the fusion core, by simply dissolving low percentages (~1%) of Uranium, Thorium, or Plutonium fluorides in the liquid fusion blanket, the tritium breeding can be substantially improved, the blanket shielding factor can be increased, and the energy output doubled. Supported by OFES and the DOE LANS Contract No. DE-AC52-06NA25396.

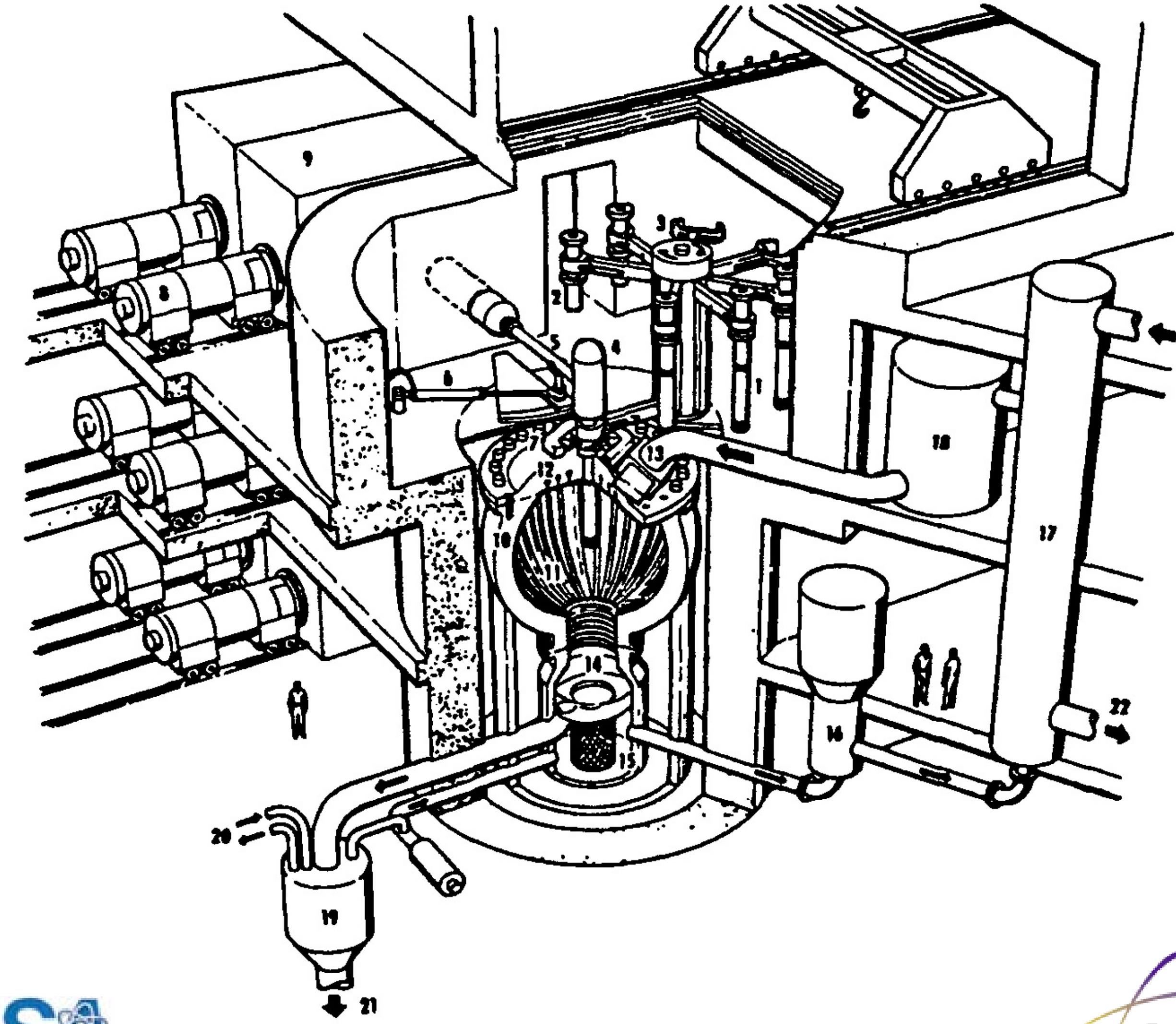
Fusion Reactor Design? Engineering concerns:

- Pulsed loading
- Chamber survival
- Driver efficiency
- Interface to standoff driver/heating systems?
- Cost of replaceable parts?
- How to get more tritium breeding?
- How to minimize recirculating power?
- Reliability (10's of millions of shots/ millions of seconds)

Reactor Design? Start from the End Point

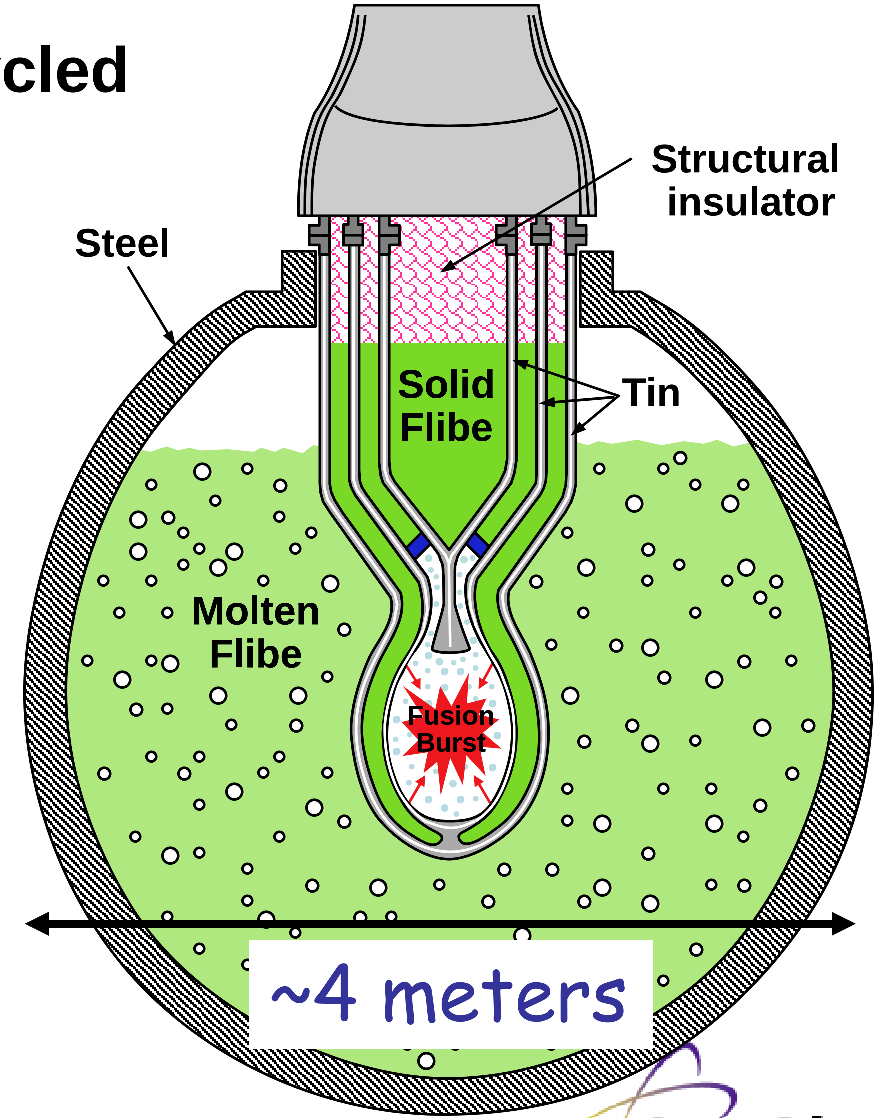
- Consider a 4.1 GigaJoule yield (1 metric ton) from a pulsed device.
- Consider a rep-rate of 0.1 Herz, which gives more time to clear the chamber.
- Pick a thermal conversion efficiency to electricity of 35%, so one would produce 1.4 GJ electric per pulse (gross, not net), or 140 MW electricity (average).
- Use a thick liquid curtains, with liquid pool at the bottom of the chamber. The liquid will absorb neutrons, and breed tritium. Have voids to dissipate shock from the explosion, and cushion the solid backing wall of the system.

LANL Fast Liner Power plant schematic (Krakowski, et al. ~ 1980)

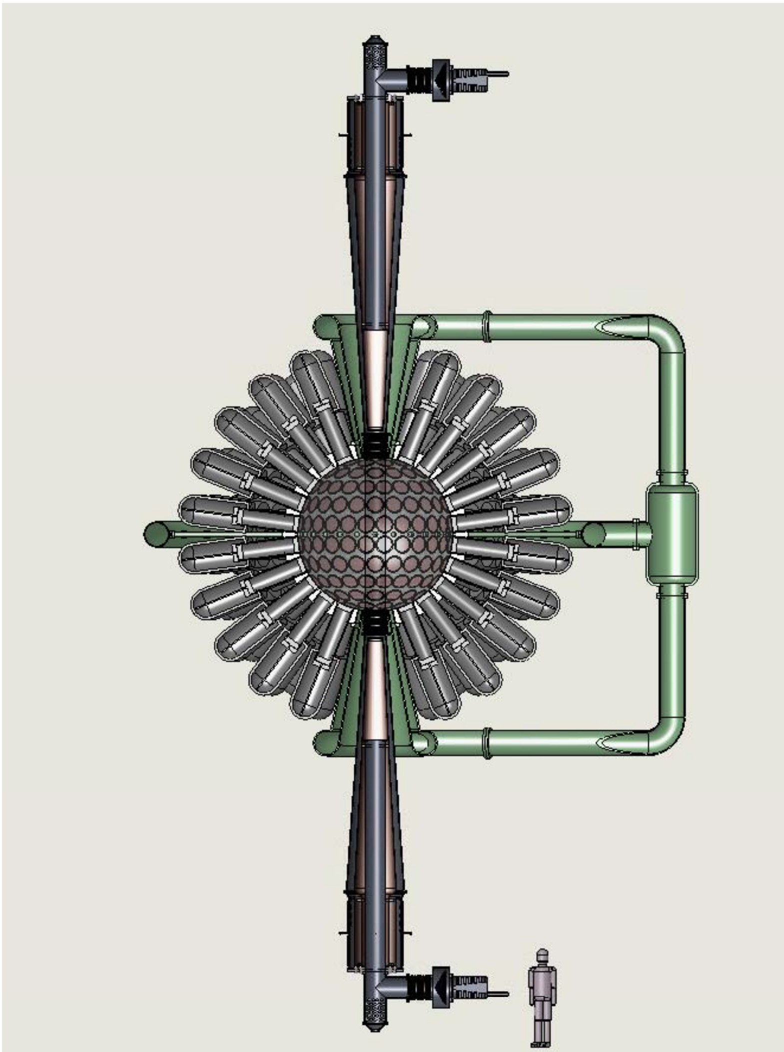


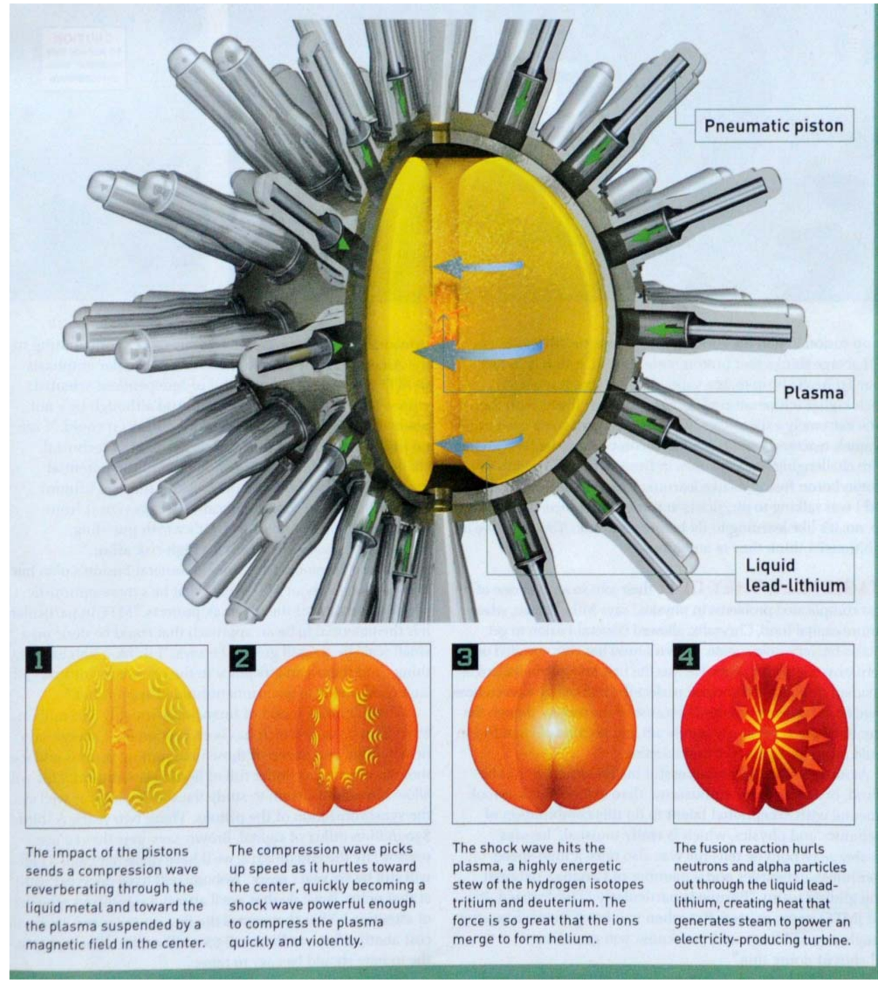
One vision of a Magnetized Target Fusion reactor

- All target material recycled
- 15 sec per pulse
- Flibe primary coolant at 550 ^oC (T_{melt} = 459 ^oC)
- Tin T_{melt} = 232 ^oC
- P. Peterson, UC Berkeley, ~1998



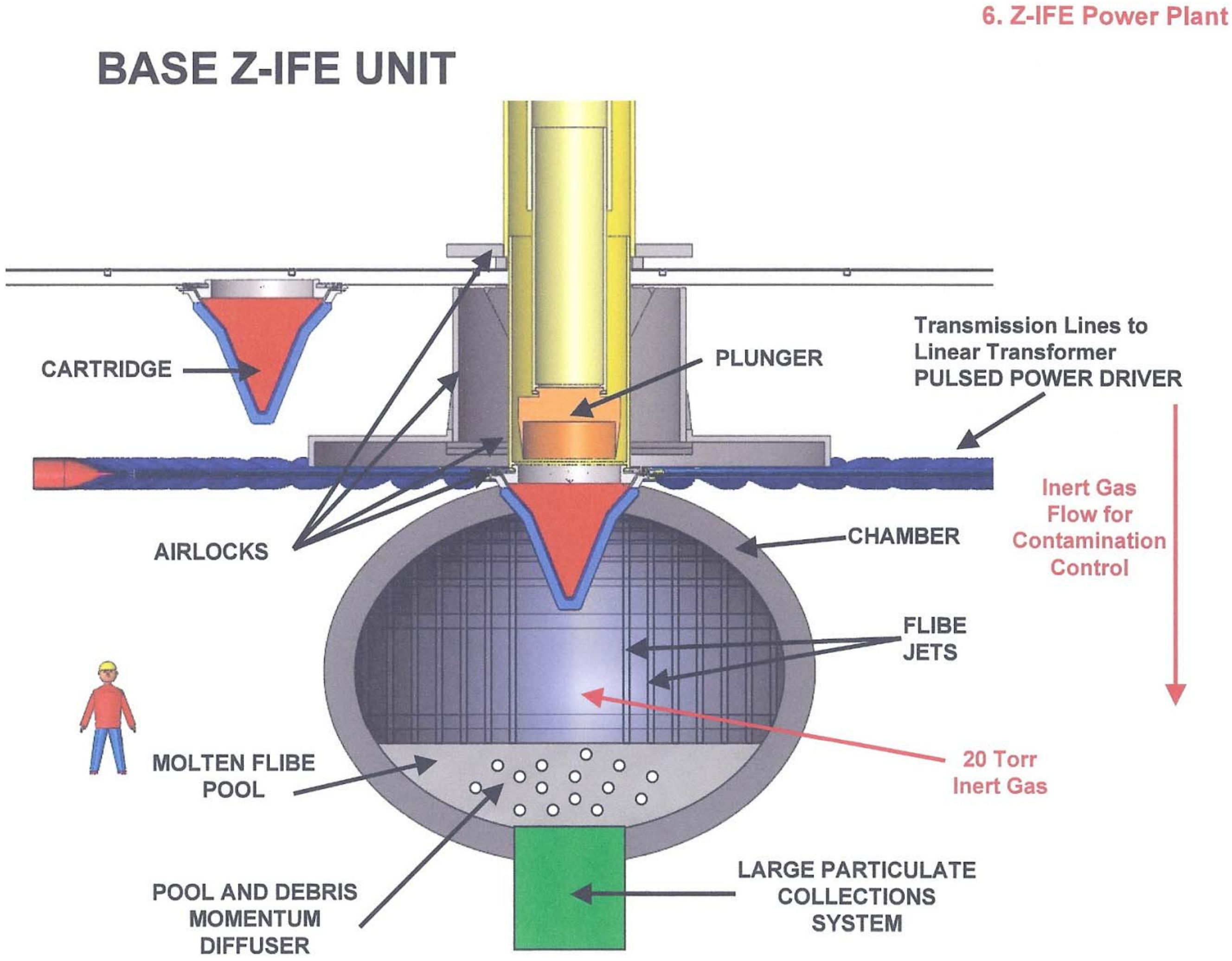
Acoustic piston drivers for MTF: General Fusion (Vancouver, Canada)





Popular Science, pg. 64-71, Jan. 2009

Sandia Z-IFE Power Plant Schematic (Craig Olson, et al.)

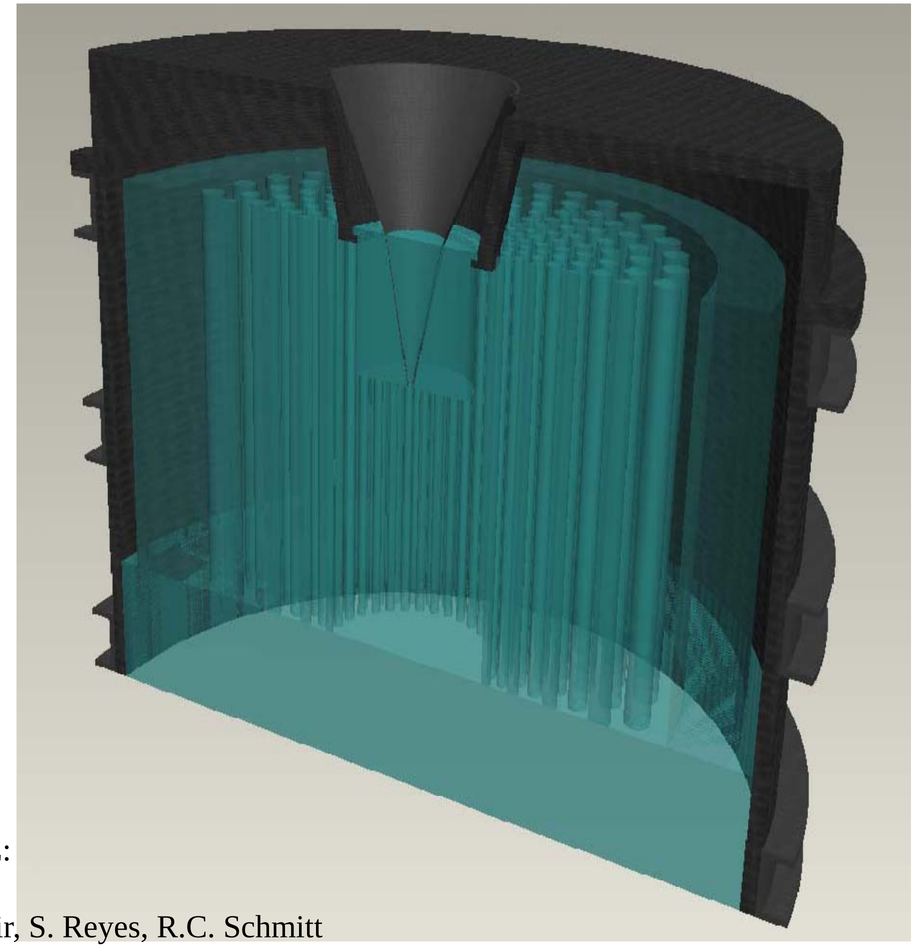


LLNL (3-month) Z-IFE concept design study*

- Higher fusion yields per chamber are more economic

- 12-m diameter chamber,
3-m thick region with
FLIBE flowing columns
(66% void fraction).
~300 m^3 of FLIBE

- Issue: Mitigation of shocks on
the final wall from 20 GJ yield
in a Z-IFE scenario
with liquid pool at bottom



*UCRL-TR-207101 Analyses in Support of Z-IFE:
LLNL Progress Report for FY-04
W.R. Meier, R.P. Abbott, J.F. Latkowski, R.W. Moir, S. Reyes, R.C. Schmitt
October 8, 2004

Can the blanket neutron energy multiplier be bigger than 1.1?

•Why is it 1.1 for "pure" fusion?….because we take an exothermic energy credit for n-Li reactions in a blanket.

•Are there other possibilites? Yes……..**Fusion-Fission Hybrids, because each fusion is good at making an energetic neutron, while each low energy neutron can cause a fission event with a lot of energy. The fusion neutron can also first be multiplied, giving even more low energy neutrons.**

•If the blanket is 0.6 meter thick hot liquid FLIBE with 10% UF4, one can protect standard solid structural elements for a long life (~30 years), while getting a tritium breeding ratio of >1.1, and an energy amplification of 1.9 (due to fission in the blanket). [Mustafa Ubeyli, Journal of Fusion Energy, Vol. 25, no. 1-2, pg 67-72, (2006)]

•So, as most of us know, if you are willing to be a fissile breeder, then it is easy to double the Q.

Thick liquid wall recirculation is not a big energy hit

• The chemical composition of pure FLIBE is Li_2BeF_4.

• If the chamber size is a cylinder, with a radius of 3 meters, and similar length, then the minimum amount of hot FLIBE out on the wall, is about 35 cubic meters.

• FLIBE has a density of 2 gm/cc, or 8.5x10^22 atoms/cc. This is an exposed blanket inventory of about 7×10^4 kg, or 70 metric tons. If it "falls" under gravity, a distance of, say, 5 meters, then the gravitational potential energy MgH is 3.5 MJ. Under gravity free-fall, it also takes only 1 second for this material to fall 5 meters.

• So you will need to invest 3.5 MW, or even twice that, continuously, to keep it circulating.

Some thick liquid wall blanket references

D. H. Berwald, et al., "Fission Suppressed Hybrid Reactor –The Fusion Breeder", Lawrence Livermore National Laboratory, Livermore, CA, UCID-19638 (1982).

R. Moir "The logic behind thick, liquid-walled, fusion concepts". LLNL UCRL-JC-115748, 1994.

R. W. Moir, R. L. Bieri, X. M. Chen, T. J. Dolan, M. A. Hoffman, et al., "HYLIFE-II: A Molten-Salt Inertial Fusion Energy Power Plant Design-Final Report," Fusion Technology, 25, 1 (January 1994) 5-25.

R. W. Moir, R. H. Bulmer, K. Gulec, P. Fogarty, B. Nelson, M. Ohnishi, M. Resnick, T. D. Rognlien, J. F. Santarius, and D. K. Sze, "Thick Liquid-Walled, Field-Reversed Configuration Magnetic Fusion Power Plant," Fusion Technology, 2, 2, Part 2 (March 2001) 758.

G. E. Rochau, and the Z-Pinch Power Plant Team, "Progress Toward the Development of an IFE Power Plant Using Z-Pinch Technology," Fusion Science and Technology, 47, 3 (April 2005) 641.

A little extra in your salt blanket: Not a new idea

J. Fredricksen, L. Gilpatrick, C. Barton, "Solubility of Cerium Trifluoride in Molten Mixtures of LiF, BeF2 and ThF4", ORNL-TM-2335, Jan. 1969

M. W. Rosenthal, R. B. Briggs, P. N. Haubenreich, "Molten Salt Reactor Program, Semiannual Progress Report", ORNL-4622, Aug 31, 1970.

R. W. Moir et al., "Fusion Breeder Reactor Designs" *Nuclear Technology/Fusion*, 4 (1983) 589-598.

Y. Gohar, "FLIBE Blanket Concept for Transmuting Transuranic Elements and Long-Lived Fission Products", ANL/TD/CP-101869 (2000).

Y. Gohar, "Fusion solution to dispose of spent nuclear fuel, transuranic elements, and highly enriched uranium" Fusion Engineering Design, 58-59, 1097 (2001).

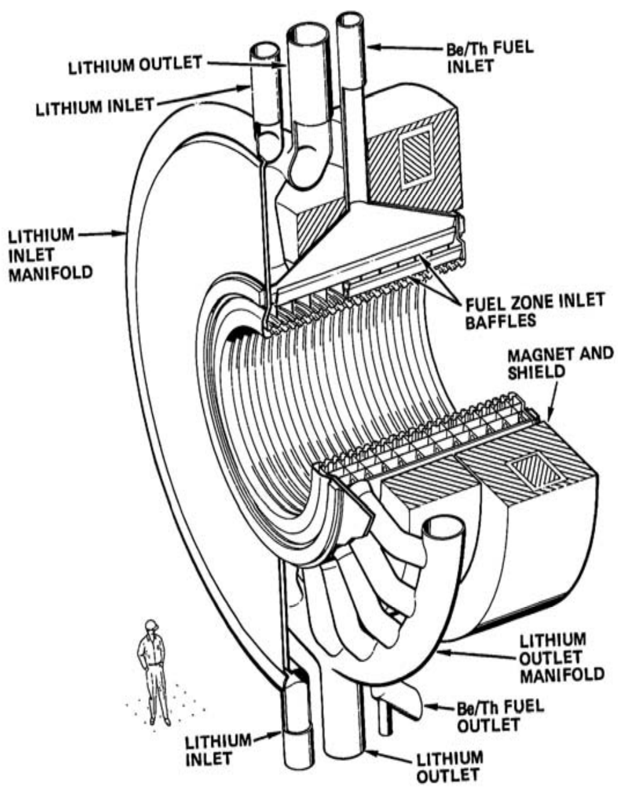
M. Ubeyli, "Neutronic performance of HYLIFE-II fusion reactor using various thorium molten salts", Annals of Nuclear Energy, 33 , 1417 (2006).

M. Ubeyli, "Potential use of molten salts bearing plutonium fluorides in a magnetic fusion energy reactor", Annals of Nuclear Energy, 35, 1087 (2008).

Some consider a two-part liquid blanket, and others like a one-component blanket

Hybrid Tandem Mirror Reactor (Berwald, et al., early 1980's)

TANDEM MIRROR FUSION BREEDER BLANKET



D. H. Berwald, R. Moir, et al., "Fission Suppressed Hybrid Reactor –The Fusion Breeder", Lawrence Livermore National Laboratory, Livermore, CA, UCID-19638 (1982).

Summary

By introducing a few percent fissile materials into a molten salt fusion blanket:

- Tritium breeding ratio is increased significantly
- Blanket shielding is improved, for the same thickness of blanket
- Output power can be doubled, with essentially no engineering changes over the pure fusion system*.
- *Hot chemical separations of fission waste products must be accomplished over time, for both insoluble and soluble compounds.