5.4.4 Tube in Shell Thorium Breeder

Figure 1 depicts another extremely promising concept that no one currently seems to be considering[1]. It's the "semi fast" (intermediate neutron speed or "epithermal") tube-in-shell configured, two-fluid thorium breeder reactor described by David LeBlanc well over a decade ago (LeBlanc 2007). Its internal core tube contains a fuel salt comprised of a low melting 2 to 1 mole-wise solvent salt mix of ^{7}LiF and BeF_2 (FLiBe, SpG~2.0) containing a surprisingly small amount of fissile (about 0.16 mole% or ~6.1E+19 atoms/cc of ^{233}U) with no fertile ^{238}U or ^{232}Th.

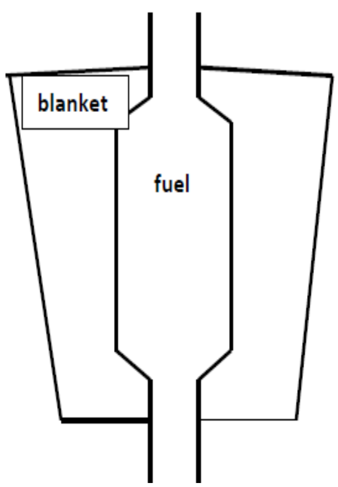

Figure 1 LeBlanc's tube in shell thorium breeder

The system's outer (aka, "shell" or blanket") side would contain a fertile salt comprised of 25 mole % ThF_4 + 75 mole % ^{7}LiF (SpG ~4.5).

1The reasons I've depicted a vertical orientation are: 1) a horizontal fuel tube would experience a huge bending force because its contents possess a much lower SpG (~2 g/cc) than that of the surrounding fertile salt (~4.3 g/cc), and 2) cranes lift up, not sideways. The latter is important because it must be designed to facilitate maintenance; i.e., core tube replacement. The accidental spill "what if" is addressed by designing the blanket tank so that if the core tank leaks, its low SpG contents would float up to its geometrically safe (pancake shaped) top, not settle into a compact ball.

Virtually all of its heat-generating fission reactions would take place within the core but sufficient of the neutrons so-produced would pass through the wall separating it from the surrounding blanket salt to regenerate at least as much new fissile as is burned within it (the fission of ^{233}U generates two fission product (FP) elements plus an average of ~2.48 neutrons[2]. About 1.1 of those neutrons are absorbed by other ^{233}U atoms within the core salt 90% of which fission thereby keeping the reaction going and producing a relatively small amount of ^{234}U therein while the remaining ~1.3 are absorbed by the system's internals (core wall metal, ^{7}Li, Be, F etc.) and the blanket salt's thorium.

It is a stretched-out version of the 4 foot core diameter, 2 fluid reactor (number 36) in Table 3 of ORNL 2751 (Alexander 1959). It is cylindrical rather than spherical with a diameter of 95 cm (48 inches x 0.78[3] relative to ORNL's original concept that emulates its neutronic characteristics. Its core is long enough (7.4 meters) to contain sufficient fuel salt (5.24 m^3) to limit mean heat generation within it to 400 kW per liter, which translates to a whole core heat generation of 2.1 GWt [4E+5*7.4*(0.95/2)^2*1000] or, assuming 48% efficient heat to electricity conversion, 1.0 GWe. Assuming ^{233}U, its within-core startup fissile requirement would be 124 kg [=6.1E+19 *1000*5.24*233/6.023E+23] which, if it were to be connected to a total of 8 m^3 worth of external piping and heat exchanger(s), translates to a total startup fissile requirement of 312 kg [124*(8+5.24)/5.24] – well under 10% of that required by any of the "fast" reactors that I've described[4]. That's a crucially important feature because the availability

2 What revived this concept to me is that, 1) both fuel and blanket salt reprocessing would be much simpler than that required by any of the U/Pu based MSR concepts I've seen so far, and 2) ^{233}U fission apparently releases about 10% more new neutrons than ORNL's researchers assumed six decades ago.(Uranium 233, 2019)

3 0.78 is the infinite length cylinder's diameter relative to that of a sphere's "buckling factor" (the relative sizes of different shaped vessels possessing the same neutron loss/leakage probablility).

of startup fissile limits the rate at which a big-enough sustainable nuclear renaissance could be implemented.

Since this breeder concept's fertile material (^{232}Th) isn't mixed in with its fissile (^{233}U)…

1)…it would not have to be separated from REE-type FP - U is easy/cheap to separate from the rare earths (and Pu), Th isn't

2) Because fertile atoms would not be absorbing neutrons within the core, achieving criticality therein would require relatively little fissile (that's why it wouldn't require much startup fissile)

3) Fuel salt clean up/reprocessing would be much easier/cheaper than it would have been with the MSBR[5] or today's LFTR concept - simply fluorinate out/collect the uranium, distill off/collect the FLiBe, & throw away everything else. The remaining waste would be easy/cheap to vitrify and there wouldn't be much of it.

Another of this brain storm's advantages is that its blanket could contain enough fertile Th to effectively shield ^{233}Pa from neutrons until it decays to ^{233}U. The LFTR concept's (next section) relatively small blanket salt volume along with its slow-moving (moderated) neutrons, renders ^{233}Pa separation/storage necessary to achieve "isobreeding" which fact greatly complicates its operation.

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4 As is the case with everything else I've written about "other people's" concepts, this section was sent off to Dr. LeBlanc to review and, if necessary, correct. As is also usual, people cc'd on my note seized upon that opportunity to point out that (unlike their own pet concept), this one is "impossible" because of its inconsistency with today's rules and customs. For instance: "*Main issue is …proliferation concerning reprocessing of both core and blanket. With the MSBR/LFTR required reprocessing system U fluorination system it is trivial to get pure HEU233 with absolutely NO U232 … 100% U233 critical mass is about the same as 93% Pu239, and far lower than 93% U235, the currently used weapons main arsenal materials.* ".In other words, in that reviewer's opinion, the purpose of NE R&D is to devise something that nobody could come up with a show stopper based upon the notion that the future's civilian power reactors would be operated by unsupervised homicidal idiots.

5 MSBR = ORNL's graphite-moderated, breeding-capable, single-salt reactor concept (Robertson 1971)

This suggests another especially worthwhile experiment for DOE's lead NE R&D laboratory to perform[6].

Its purpose would be to see if the specially fuel/fissile efficient, original two salt thorium breeder concept that LeBlanc's is based upon would actually work. To help understand what I'm talking about, read the following chapter from ORLN's iconic book "Fluid Fueled Reactors" (https://energyfromthorium.com/pdf/FFR_chap14.pdf) - especially its section having to do with their/its concept's configuration (spherical fuel salt tank within a bigger blanket salt tank), and neutronic performance with especial attention to its "case numbers" 41 and 42 (three and four foot diameter cores, ^{233}U fissile and no thorium in the fuel salt)

Here's why the USA's lead NE R&D team should study it. :

- that concept's "clean" core should require very little startup fissile/useful output which means that it could render a rapid nuclear energy build-out possible
- its fuel & blanket salt streams should be far easier/cheaper to "reprocess" than any solid-fueled breeder's seed/blanket rods, prisms, or balls would be (save money & reduce out- of- core fissile inventory)
- if it does work (can isobreed or better), it shouldn't be difficult to scale up power-wise by switching to a neutronically equivalent elongated configuration (Leblanc's tube-in-shell concept).
- it wouldn't generate plutonium

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6 If DOE's experts "can't" study this concept because its core would contain bomb-grade fissile, maybe the US Navy's could.

- it wouldn't generate 75-100 tonnes of crapped up graphite moderator radwaste per GWe-year.
- it's uniquely simple to model
- it should be cheap to build
- it should be easy to start, operate, and shut down
- because MSRs are natural load followers electrical utilities wouldn't have to invest in and their customers pay for, batteries, "peakers" or any other of the components of Dr. Moniz et als' "all of the above" future energy scenario.

As far as its material requirements are concerned, the one good thing about DOE's approach to managing whatever its decision makers deem to be "waste" is that it's incredibly inefficient and therefore slow. The consequence is that several hundred kg of fairly pure ^{233}U probably still lingers somewhere within the DOE Complex (the AEC's contractors made roughly 10 times as much as this experiment would require to perform its Shippingport thermal PWR breeder demo). Second, my ball park calculations suggest that the salt mixture utilized for ORNL's MSRE demonstration contained about 470 kg of isotopically pure ^{7}Li which should also be more than enough to do those tests. Finally, there's been a great deal of materials science work done since ORNL's fluid fueled reactor book was written (esp. in the ceramics and carbon-based composite fields) which ought to improve the concept's performance[7] & render the study relatively easy to do.

7 For instance, its CR (breeding performance) would be much enhanced if its core tube could be made of some sort of carbon or carbon-silicon composite instead of INOR 8 (aka Hastalloy n).

If those tests indicate that Leblanc's concept would likely work, another old report suggests that thorium blanketed, reactor grade Pu metal-fueled LMFBRs could quickly produce enough ^{233}U to start up lots of them (Chang et al 1977). That report's Table V indicates that a so-configured 1 GWe LMFBR would generate about 384 kg of ^{233}U per year – more than enough to start up an equally powerful tube-in-shell thorium breeder; i.e., a single GWe's worth of plutonium burned in that fashion could start up another breeder capable of generating the same amount of power "forever". On the other hand it would take the ^{233}U generated by about ten such reactors to start up another such LMFBR.