Neutron Capture, Structure Damage, and Economics of Various Nuclear Sources

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Fission

ν = 2.5 neutrons/fission = 2.5 neutrons/200 MeV ($E_{nts} \approx$ 2.5 MeV)

Of these neutrons, 1.0 must go to close fission chain; leaving 1.5 to be destroyed. But this 1.5 is part of the reactor *neutron conservation* effort. Thus at most 0.3 can be captured controllably in ^{10}B rods; leaving ca. 1.2 for n,γ capture that produces radioisotopes.

Hence for fission: M_{ri} = 1.2 neutrons/200 MeV is a measure of radioisotope mass produced in operation.

M_{ri}(fission) = 6 x 10^{-3} = measure of *radioisotopes mass produced*.

DT Fusion

ν = 1.0 neutrons/fusion = 1.0 neutrons / 21 MeV (E_{nts} = 14.1 Mev)

Of these, all 1.0 must go to close fusion chain via ^{6}Li-T-breeding. Thus the initial 1.0 must multiplied up in a blanket multiplier. Typically 1.0 x blanket → 1.3 neutrons/fusion is about the best that can be done in large tokamaks. This leaves 0.3 to be destroyed. But this 0.3 is part of the neutron conservation effort, thus can not be strongly coupled to ^{10}B capture (same problem as for fission — i.e. there is not much neutron excess to “waste” in ^{10}B).

Thus nearly all of the 0.3 goes into radioisotopes, yielding M_{ri} = 0.3/21 MeV.

M_{ri}(DT) = 1.4 x 10^{-2} = *2.5x fission radioisotope production*

DD 1/2-Cat

ν = 1.0 neutrons/2.5 DD equivalent fusions = 0.4 neutrons/DD reaction; (E_{nts} = 2.45 MeV; E_{fusion} = 10.7 MeV, including blanket)

No use is required of these neutrons, thus *NO EFFORT NEED BE PUT INTO NEUTRON CONSERVATION IN THIS SYSTEM.*

On the contrary — the blanket design should maximize neutron capture in ^{10}B and minimize neutron capture in radioisotope metal. This can be done to extent of about 5% into radioisotope metal, 95% into ^{10}B (giant absorption cross-section). Thus neutrons into radioisotopes are 0.05 x 0.4 = 0.02/fusion and M_{ri}(DD 1/2-cat) = 0.02/10.7 MeV = 1/535

M_{ri}(DD 1/2-cat) = 2 x to^{-3} = *0.3x fission radioisotope production*

Structure Damage

P_{nts}/P_{total} = 0.09 for DD 1/2-cat; = 0.05 for fission, thus core structure damage in 1/2-cat is at twice the rate of core structure damage in fission (PWR).

If PWR life is T_{PWR} years, then DD 1/2-cat life is $T_{PWR}/2$ (due to neutron damage).

OR by comparison with DT: neutron damage in DT is at 20x rate in DD 1/2-cat. If DT structures survive 3 years, DD 1/2-cat will live 60 years.

OR take 12 MWyear/m^2 (neutrons) as lifetime dose for 2.5 MeV neutrons (this is too low by 2x for actual fact). With this, in a DD 1/2-cat device with 4 MW/m^2 (thermal) on first wall and $P_{nts}/P_{total} = 0.09$ (as above), structure damage lifetime will be (0.91/0.09)(12/4) = *30 years*.

DD 1/2-cat Economics

BoP is the same for PWR and DD 1/2-cat. BoP cost = 65% of plant cost; PWR cost = 35%. But DD 1/2-cat Fusion Power Core (FPC) cost = 1/3 of PWR cost, thus DD 1/2-cat system cost is (BoP + FPC) = (0.65 + 0.12) = 0.77 of PWR plant cost.

Thus DD 1/2-cat power cost will be ~0.77 or less of PWR power cost (ignoring added PWR costs for handling and disposal of FP wastes).

p^{11}B Economics

1. Take the simplest steam cycle for p^{11}B system. NO *direct* conversion, $\eta = 0.33$ efficiency. Then p^{11}B BoP = PWR BoP, but p^{11}B FPC ≤ PWR costs, so plant capital cost is less.
2. IF direct conversion is used, then entire BoP is reduced (NO turbines, etc). Reduced to ca. 5-10% of previous plant (for startup needs, etc.). Typically, p^{11}B system BoP can be as low as 0.1 BoP(PWR).
3. But p^{11}B FPC is costly; with 2 MeV AC/DC convertors, high voltage transformers, etc. Thus FPC costs ≈ 1-2x PWR FPC, so *power costs* ≈ 0.1 + (1-2)(0.35) = 0.4-0.8 PWR costs.

Summary

System	Power Cost / PWR Power Cost
DD 1/2-cat; steam cycle; $\eta = 0.33$	< 0.77
p^{11}B; steam cycle; $\eta \approx 0.33$	0.9 - 1.0
p11B; Direct Conversion; $\eta = 0.80$	0.4 - 0.8