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Fission-Fusion Neutron Source

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We are currently pursuing a novel concept for producing intense pulses of neutrons using the DT fusion reaction. In this new scheme the heating of the DT is accomplished using fission fragments rather than ion beams as in conventional magnet fusion schemes or lasers in ICF schemes. This has the great advantage that there is no need for any large auxiliary power source. Our scheme does require large magnetic fields, but generating these fields, e.g. with superconducting magnets, requires only a modest power source. As a source of fission fragments we propose using a dusty reactor concept introduced some time ago by one of us (RC) [1]. This reactor would operate as a thermal neutron reactor and use as fuel micron sized pellets of UC.

Our scheme for using fission fragments to produce intense pulses of 14 MeV neutrons is based on the fission fragment (FF) rocket idea [2]. In the FF rocket scheme it was contemplated that the FFs produced in a low density reactor core would then be guided out of the reactor by large magnetic fields. In our fission-fusion neutron source the FFs exiting a FF rocket would be used to heat DT gas confined in an adjacent magnetic trap (see Fig 1).

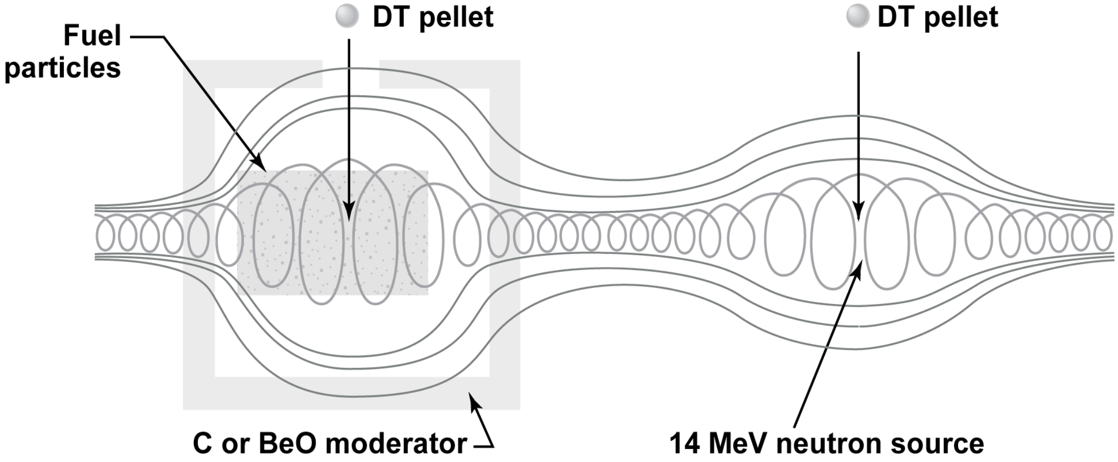

Fig. 1 Scheme for using fission fragments to produce fusion neutrons

An advantage of our concept is that the possibilities and limitations for generating self-sustaining fission are generally well understood. For example, a reactor power of 100 MW is well within the temperature limits that would allow passive steady state radiative cooling of a reactor core and moderator. The use of external cooling might allow transient powers as high as ~1 GW. Our hope is that at a transient reactor power < 1GW one could heat a small mass of DT to a temperature > 1 keV, at which point the temperature of the DT will "run away" due to boosting of the fission rate by the DT fusion neutrons and self-heating of the DT by alpha particles. Of course, at keV temperatures the DT can no longer be confined in a magnet trap for more than a short time; perhaps for only the Bohm diffusion time, which is about a millisecond. Even so we believe that using our scheme one will be able to produce bursts of up to 10^{20} neutrons.

Although we have already 10 years ago estimated the critical masses of Pu239 and U235 required for the fission fragment rocket, we show in Table 1 some recent results for critical masses calculated using the Los Alamos Monte Carlo neutron transport code MCNP. The fuel was assumed to be low density homogeneous U235 in the chemical form UD or UC, and the moderator was chosen to be either deuterated polyethylene or heavy water.

Table 1

Fuel	Moderator	Fuel dimensions	Average fuel density	Critical mass
UD	110 cm CD_2	4 m x 5 m	0.2 mg/cm^3	12 kg
UD	250 cm CD_2	6 m x 5 m	0.1 mg/cm^3	14 kg
UC	200 cm D_2O	6 m x 5 m	0.1 mg/ cm^3	14 kg

The last line in Table 1 is our current "baseline" configuration. The DT heating rate is determined the reactor power and the number of U atoms within a fission fragment mean free path. In our baseline reactor configuration about 20% of the fission fragments contribute to heating the DT. One could achieve higher efficiencies for using the reactor power to heat DT by lowering the fuel density. However, this would require increasing the reactor size in order to keep the critical mass constant, and a reactor with significantly higher efficiency might be too large to be practical. . For our baseline reactor, a transient reactor power ~200 MW would be needed to heat 1 gm of DT to a keV. Selected values for the FF heating, α-particle heating, and radiation energy loss in a layer of DT external to the fuel for our baseline reactor operating at a transient power of 200 MW are given in Table 2:

Table 2

T(keV)	Initial FF heating	Alpha heating	Bremsstrahlung loss	Boosted FF heating
1	2 MW/m^3	3 kW/m^3	5 kW/m^3	50 kW/m^3
2	2 MW/m^3	0.1 MW/m^3	7 kW/m^3	2 MW/m^3
5	2 MW/m^3	5 MW/m^3	11 kW/m^3	100 MW/m^3

The bremsstrahlung loss in Table 2 assumed $n_{D,T} = 10^{15} cm^{-3}$. These estimates suggest that a transient reactor power of 200 MW might be sufficient to cause the DT to "run away". One question that always needs to be kept in mind though when considering whether DT can be heated to the point where self-sustaining fusion reactions are possible is whether radiation from impurities in the plasma prevents its heating. In our case impurities in the form of fission fragments are always present, and so an obvious question whether radiation from these fission fragments can prevent heating of the DT. However, even after losing 99% of their energy, FFs are still moving with a velocity of 10^8 cm/sec; therefore even with a ~10^{19} FFs sec^{-1} source (corresponding to a reactor power ~ 200MW), the density of FFs in the magnetic trap is very low (~10^6 cm^{-3}). Therefore bound-free radiation from these fission fragments is negligible. Of course, impurities may exist in the fuel region due to spallation of the fuel. We hope to mitigate this problem be introducing a layer of pure DT around the fuel.

What may not be negligible is bremsstrahlung radiation from the DT plasma. At a temperature of 1 keV the bremsstrahlung energy loss is $\approx (n_{DT}/10^{17} cm^{-3})^2$ MW/m^3 . This limits the density of the DT gas to an atomic density ~10^{17} cm^{-3}. This means that the range of the FFs in the DT will be on the order of 10s of meters [3]. Our hope is that this range is not too long because of cycling of the fission fragments in a strong magnetic field. The magnetic rigidity *Br* of fission fragments is $\approx$ 0.6 T-m; therefore most of the fission fragments can be confined within the moderator if the magnetic field varies from about 0.5 Tesla along the central axis to about 2 Tesla at the edge of the fuel.

Proof of Principle Experiments

Dusty plasmas are of great interest in astrophysical contexts and for semiconductor processing. In fact the dusty plasmas we require for our reactor core are not very different from the dusty plasmas commonly used for plasma etching in the semiconductor chip industry. These plasma etching machines typically use 2 μm diameter SiO_2 particles with a density of 10^8 particles per cc. Remarkably, this is essentially identical with our standard model for the reactor core, which would use ~1 μm diameter UC particles with a density ~10^8 particles per cm^{-3}.

We contemplate that the fuel particles in our reactor core can be kept levitated using electrostatic fields. Experiments demonstrating this possibility using micron sized CeO_2 particles have been carried out at the High Energy Density Research Center in Russia [4] In Fig. 2 we a picture of the suspended CeO_2 particles in the Russian experiments where the CeO_2 particles have become charged as a result of exposure to a Cf^{252} spontaneous fission source. The particles are kept apart by their mutual electrostatic repulsion.

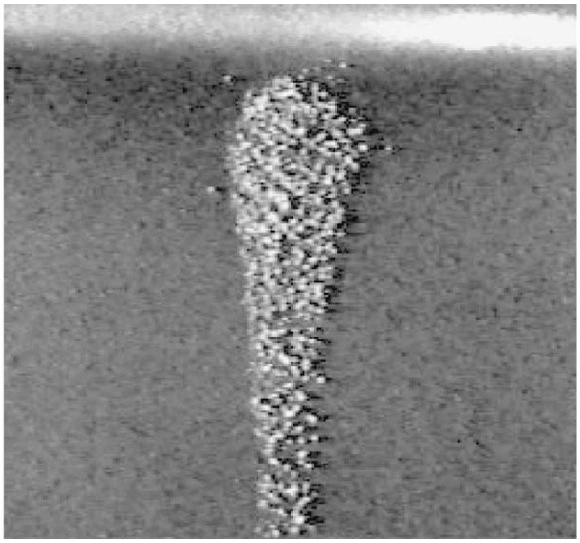

Fig. 2 Suspended micron size CeO_2 particles

As a first step towards evaluating the feasibility of suspending a critical mass of micron sized UC particles in a vacuum, it will be necessary to understand how the emission of fission fragments and exposure to fission gamma rays in the presence of a hydrogen plasma affects their charge state. As a first experiment we propose measuring the equilibrium charge of an Am or Cf grain suspended in a Paul trap in the presence of a gamma source. Once the charging of micron sized fuel particles is understood, we can proceed to design a prototype dusty reactor neutron source.

References

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