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Symbiosis of near breeder HTR's with hybrid fusion reactors

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ADVANCED FUEL CYCLE AND REACTOR CONCEPTS

SYMBIOSIS OF NEAR BREEDER HTR'S WITH HYBRID FUSION REACTORS

by

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Contribution to
Summary Report on the HTR and its Fuel Cycle Options
Chapter V

In this contribution to INFCE a symbiotic fusion/fission reactor system, consisting of a hybrid beam-driven micro-explosion fusion reactor (HMER) and associated high-temperature gas-cooled reactors (HTR) with a coupled fuel cycle, is proposed. This system is similar to the well known Fast Breeder/ Near Breeder HTR symbiosis except that the fast fission breeder - running on the U/Pu-cycle in the core and the axial blankets and breeding the surplus fissile material as U-233 in its radial thorium metal or thorium oxide blankets - is replaced by a hybrid micro-explosion DT fusion reactor.

Due to the excellent breeding capability of the hybrid fusion system only a small fusion power capacity relative to the fission power produced by the NB-HTRs is necessary. I.e. in terms of "Kg fissile produced per MW_{th}-yr" a hybrid fusion system produces up to 10 times more fissile material than a fast fission breeder of the present design. A hybrid micro-explosion fusion reactor can therefore sustain in equilibrium up to 30 HTRs even with denatured U-233/U-238 fuel. Also in contrast to a fission breeder, no initial fission material is necessary to start the hybrid fusion breeder. This latter fact would make it possible to establish a very fast growing HTR-reactor capacity in a transient build-up phase by installing only a moderate capacity of hybrid micro-explosion reactors.

With regard to the technological maturity of the proposed system, it is clear that the inertial fusion confinement system is less advanced than the fast fission breeder. However, the development of the former is gathering speed and, in discussing advanced fuel cycles for HTRs, a possibility for consideration is the breeding of U-233 fuel using fusion neutrons.

The concept of producing fissile materials (mainly Pu-239 and U-233) in fusion hybrids is not new and has been described in many articles. The new aspect within the framework of INFCE is the "proliferation resistance" of the coupled fuel cycle of HMER/HTRs in comparison with that of the fission breeders/HTR symbiosis.

Should the hybrid micro-explosion fusion reactor be developed as a commercial power plant, then a small number of such units could be installed in safeguarded zones. Their blankets could contain thorium to be converted in U-233, lithium to produce enough tritium to maintain the DT fuel cycle, beryllium and/or depleted uranium as neutron multipliers. The blanket energy production should be kept small in order to optimize the production of fissile fuel. There are a great deal of such lay-outs of blankets in the open literature and it ought to be possible to generate 1 to 1.5 kg U-233 per MW_{th}-yr.

Since no initial fissile inventory is necessary and therefore no criticality condition has to be taken into account one could homogeneously blend the fertile material (in this case thorium) in the blanket with a certain amount of natural or depleted uranium to get the bred U-233 fuel directly in a denatured form. After reprocessing and enrichment of U-233 to the denatured standard norm of 20 % this blended, non-weapon - grade fuel could be used to fuel HTRs which are operated on a medium enriched U-233 fuel cycle (MEU-233). Aside from perhaps a small amount of relatively clean plutonium produced in the fusion blanket there would be no large amounts of weapons-grade materials at all in the fuel of the coupled symbiotic fuel cycle.

Concerning the irradiated fuel of HTRs which have to be trans-ported back to the safeguarded zone one has to distinguish between the plutonium and the U-233 produced. Due to the very high burn-up of the denatured fuel in the HTRs (up to 100'000 MWd/t) the plutonium produced is very dirty (Pu239+Pu241/Pu240+Pu242 ≈ 0.35 - 0.4) and cannot be used as a weapon-grade material. There is admittedly the problem of the U-233 bred in the HTRs. In the case of the mixed-particle concept (feed and breed mixed) this is of minor importance. In the case of the two-particle concept (feed and breed in separate pebbles) there is still the possibility of using "dirty thorium" (i.e. thorium with a relatively high content - a few hundred ppm - of Th-230) in order to generate a relatively large amount of U-232 whose daughter products emit hard gamma rays and would make it difficult for thieves to handle irradiated breed elements. Thorium containing sufficient amounts of its isotope Th-230 is available from mines which contain both, thorium and uranium. The suggestion here is to make "systematic use of the dirty thorium" to make an HTR fuel cycle more proliferation-resistent.

Another possibility is to isotopically denature the plutonium bred in an HTR containing U-238. The idea is to mix small amounts of Np-237 with the fuel in order to produce Pu-238 which is a strong α-emitter. These α-particles will then produce a lot of neutrons via the α,n reaction in the oxygen of the ceramic oxide fuel kernels. Thus, a strong neutron radiation is present in irradiated fuels which make the handling of such fuel more difficult.

Conclusions:

We all know that in the framework of the peaceful use of nuclear energy there is no inherently and completely foolproof fuel cylce with absolute "proliferation resistance". Even in isotopically denatured fuels such as 20 % U-233 in U-238, a relatively small amount of Separative Work Units (SWU) is necessary to fully enrich the U-233 by means of e.g. a centrifuge compared with the conventional enrichment of U-235 from natural uranium: Firstly one starts with a higher concentration of the fissile isotope in question and secondly the much larger mass difference between U-233 and U-238 makes separation significantly easier.

A further drawback of denatured fuel cycles is that, from the neutron physics and economics points of view, the high enriched fuel cycle (HEU), with either U-235 or U-233, is clearly the best one in an HTR, particularly for the case of a near breeder design. Such near breeders should be the ultimate goal of HTR fuel cycle development because of the substantial savings of natural uranium. There should be no U-238, and in the consequence no plutonium in an HTR.

We believe that the problem of weapons proliferation requires political solutions which can at best be eased by supplementary technological methods. The possibility of producing fissile material exists in any system with available free neutrons. Fusion systems also (both DT and DD cycles) produce abundant free neutrons. We are thus faced with the constant problem of "safeguarding free neutrons". Only an eventual transition to processes such as charged particle reactions (eg. $p-^{11}B$, $D-^{6}Li$, etc) could circumvent the fundamental problem.

The main argument which I want to make here, is that a future fusion hybrid/HTR symbiotic system will introduce neither more nor less proliferation problems than the fission breeder/HTR symbiosis. The sensitive parts of that system (hybrid fusion reactor, reprocessing, fuel fabrication, waste disposal) could equally well be located in a safeguarded zone.

Since the introduction of fusion energy will most likely be introduced via the intermediary of the hybrid system (facilitating the break-even of the energy balance) and since the fusion hybrid is such an excellent "fuel factory" for HTRs, one should assess the problems on a realistic basis and should not jeopardize a practically limitless future source of energy by over-emphasis of the proliferation issue.

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