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Fusion devices as neutron sources for FFH (Fusion Fission Hybrid Reactors): Analysis of tokamak parameters , readiness level and design of concept validation experiments

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The fusion neutron sources needed for FFH (Fusion-Fission Hybrid) devices are not available so far, and the blankets integrating the fusion and fission characteristics need to be projected and validated. The concrete validation of the FFH concept is needed. Starting from the figures of a neutron source needed for FFH, the paper is devoted to: i) the determination of parameters for a tokamak fusion source; ii) analysis of the technology readiness level [1] of tokamak as neutron sources and iii) possible design of experiments for the validation of the FFH concept on presently available devices. Basic requirements for FFH neutron source are : Q=2-3 (Fusion gain factor), fusion power D-T >60MW, Heating power 30MW , power flux on the divertor <5MW/m2 , blanket Li+U238 or Th232. The determination of optimal parameters of tokamak devices is linked to the scaling laws on the basis of the description of a plasma state. For reactor plasmas (deuterium-tritium) the α-particle power ($P\alpha$) must be introduced as an important contribution to plasma heating. In this case (the reactor plasma) $P\alpha$, the gain factor Q (=fusion power/heating power) and the slowing down time of the alpha particles (τSD) the characteristic time for transfer on energy from alpha articles to electrons, are parameters defining the plasma state. The following set of parameters are a basis for the definition of the scaling laws for fusion reactors:1.Q=Q0 fixed ;2. $\tau SD = \Lambda SD\ \tau E$.($\Lambda SD \le 1$) (slowing down time of alpha particles ≤ energy confinement time): this is true for ITER, Te≤20keV; ΛSD depends upon the device;3. $P\alpha = \Lambda LH\ PLH$ (ΛLH >1.5 , a number), the alpha heating is sufficient to keep the plasma in H-mode, PLH is the power threshold for entering the H-mode ; 4. The energy confinement scaling law is ITER IPB98y2 and the scaling for the power threshold for the transition to the H-mode scaling PLH ≈ Alh B n3/4 R2. The scaling parameter linking equivalent fusion plasmas is: SFR =scaling parameter for fusion reactors = R B 4/3 A-1 Q0 1/3 . Following this scaling laws and using as reference the Q=0.55 discharge realized on JET DTE1 experiment , a Q=2 device has major radius R=2m, magnetic field 5T,aspect ratio A=2.5. The technology readiness level of the various subsystems of a tokamak can be determined and TRL≈4 can be given to the plasma heating systems and superconductor magnets , while only to the electron cyclotron resonance heating can be given TRL≈6 . From the point of view of the validation of the concept, the coupling of a fusion device to a multiplying fission medium (FFH) can be seen as one very specific case of the coupling of an intense high energy neutron source to a fission system. In the recent past the case of Accelerator Driven Systems (ADS) was considered, in particular in the frame of waste management strategies. In order to validate the concept, an experimental validation strategy was set up and several relatively large experiments were realized in a European frame [2]. The same strategy of "validation by components"can be applied to FFH concept: apart from the realization of a fusion source , the validation concerns the subcritical region (with a "standard"fuel), the eventual presence of buffer regions between the fusion source and the fission blanket, the presence of specific shielding zones. The experimental program should be devoted to the study of the sub criticality, of the power distributions, and of some significant transmutation rates of key isotopes. Among the validation experiments performed in the past, some experiments in the frame of the MUSE program performed at the MASURCA facility at CEA Cadarache (France) and the experiments pre-TRADE performed at ENEA Casaccia (Italy) on the TRIGA RC-1 reactor [2] can be considered as an initial database to be used in a step-by- step validation of the FFH concept. New subcriticality measurements should also be envisaged, using techniques developed recently in different laboratories. These measurements are envisaged in the Casaccia TRIGA reactor. A phase of validation should be envisaged, where the actual coupling of a small size fusion device should be coupled to a multiplying fission blanket. A preliminary evaluation, by means of the MCNP code, has been carried out by considering the coupling of an external source (DD and DT type) with the TRIGA reactor in subcritical configuration, in order to compare the neutron spectra in different TRIGA positions, and for different source positions, with the fusion spectra entering a fusion blanket. Two different positions for the external source have been considered: one in the Central Channel (named Source CC) and one in the Radial Channel A (named Source PC) for both DD and DT spectra. Once defined the TRIGA subcritical configuration (keff=0.95), obtained by removing all the fuel elements in the first ring plus four elements in the second ring, the neutron spectra in some elements, have been evaluated for each external source position and type (DD or DT).

1. F P Orsitto et al, Diagnostics and control for the steady state and pulsed tokamak DEMO, Nuclear Fusion 56(2016) 020009

2. "Research Reactors for the development of materials and fuels for innovative nuclear energy systems", IAEA NUCLEAR ENERGY SERIES NO. NP-T-5.8,2017.

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