# Synergy of Fission and Fusion: the path to clean nuclear enerGy system

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The problem of long-term management of high-level (HLW) wastes has been the major factor to humper large scale nuclear power development since its emerging as an industrial power technology. In Europe it was recently translated into debate on taxonomy approach developing technical screening criteria for climate objectives. In 2020 nuclear power technical expert group did not recommend to include nuclear power in taxonomy in a view of the HLW problem [1]. However nuclear scientific community continues to emphasize that nuclear technology has an inherent potential to solve the HLW problem through recycling and transmutation. It was clearly stated in the report of the Joint Research Centre in 2021 that significant research effort has been devoted to maximising the fraction of spent nuclear fuel that can be recycled in nuclear reactors and reducing the long-term radiotoxicity of HLW to be disposed of in the geological repository [2]. In Russian Federation within the framework of “Breakthrough” (“Proryv” in Rus) the first concrete was poured in the foundation of reactor building of lead-cooled fast reactor BREST-300 that will prove industrial feasibility to closed fuel cycle by 2030. This new reality paths its way into new project under umbrella of the IAEA activity on Innovative Nuclear Reactors and Fuel Cycles (INPRO) entitled “Step Forward” to derive practicable conclusions for the potential of an initial deployment of small numbers of particular innovative nuclear energy installations ranking from fast reactors to fission-fusion hybrids to contribute to a notable reduction of spent nuclear fuel inventory. This particular paper emphasizes fusion technology as a source of neutrons that provides excellent neutronics environments to transmute the long-lived fission products (FP) that drive cumulative radioactivity release from deep geological storage within hundreds of thousands years [3].

Generation of neutron excess is the key to transmutation of radiowastes. It is generally defined as a difference between number of neutrons released as a result of fission reaction and neutrons needed to sustain chain reaction including associated parasitic capture and leakage. Within the family of fission reactors it is fission reaction induced by high energy (fast) neutrons that gives appreciable neutron excess. That is why the majority of the designs of the Generation-IV reactors belongs the family of fast reactors that can provide both fuel breeding and transmutation of some radiowastes, mainly those belonging to transuranics.

Traditional approach to apply fusion phenomenon for power generation in the D-T case at least considers

* tritium breeding in situ that requires neutron multiplication induced by 14 MeV fusion neutron;
* neutron moderation in the blanket to approach positive energy balance in a single fusion power facility.

From the view point of neutron excess it resembles neutron requirements to sustain chain reaction in fission reactions. From the view point of neutronics fusion has one distinct advantage: neutron production zone (plasma) and the zone of neutron utilization (blanket) are spatially separated. That reveals the flexibility in creating neutron spectra in the blanket that might be soft enough to transmute FP with low neutron capture cross-section (see Figure 1). Table 1 gives an illustration of mean life-time of Cs-135 (one of the most problematic long-lived FP nuclides with half-life 2.3 106 yrs) in different neutronics environments including D-T based fusion neutron source (FNS) with the neutron wall load of 1 MW/m2.

COMP_PWR_FBR

*FIG. 1. Comparison of neutronics in thermal and fast fission reactors and in fusion neutron source based on DT- plasma [3]*

TABLE 1. MEAN LIFE-TIME of Cs-135

|  |  |  |  |
| --- | --- | --- | --- |
|  | Thermal spectra  (1 eV) | Fast spectra  (0.2 MeV) | FNS |
| Capture cross-section (b) | 1.3 | 0.07 | 3.12 |
| Neutron flux (n/(cm2 s)  Mean life time | 1014  240 | 1015  450 | 4.75 1014  21 |

At first wall load of 2.5 MW/m2 mean life-time of 135Cs drops to 7.34 yrs. PWR reactor park supported by one FNS appears to be about 29 GWe and the share of power associated with cesium transmutation is 4% (cesium accumulation rate is 70 kg/GWel yr for typical PWR with burnup of 33 GWd/t was assumed for estimation) [4].

With such an excellent transmutation characteristics positive energy balance in a single fusion facility is welcome but not absolutely necessary if we consider hybrid nuclear energy system consisting of fusion reactors and fusion-based transmuters. Power to feed plasma could be supplied by fission reactors. Regardless of *Q*-value it gives the chance to achieve synergistic effect through fission-fusion combination that could solve the problem of long-lived radiotoxicity in deep geological storage and bring nuclear power to the category of “green” energy sources.

References

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