Activation Analysis for Two Molten Salt Dual-Coolant Blanket Concepts for the US Demo Reactor

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The US has considered, among other options, two blanket concepts for Demo reactor in which helium is primarily used to cool the first wall (FW) and structure whereas molten salt (MS) is used as both coolant and breeder. The Demo reactor has a maximum neutron wall load, NWL, of 3 MW/m^2 at the Outboard (OB) (~2 MW/m^2 at the IB) and an average NWL of ~2.5 MW/m^2 at the OB (~1.6 MW/m2 at the IB). Conventional reduced activation ferritic steel (RAFS, F82H) is used as the structural material in both blanket concepts. The "Flibe" MS, with mole ratio 1:1 of LiF and BeF_2, is used in the first option with 50% Li-6 enrichment while the "Flinabe", with mole ratio of 1:1:1 of LiF, NaF, and BeF_2, is used in the second option with 60% Li-6 enrichment. The Flibe with the 1:1 mole ratio was chosen due to its lower melting point of ~380^{o}C as opposed to ~470 ^{o}C with a mole ratio of 2:1. Low melting point has the advantage of widening the coolant operating temperature window and hence improving the thermal efficiency of the plant. Flinabe has also lower melting point (~305^{o}C) but its tritium breeding capability, characterized by the attainable tritium breeding ratio TBR, is lower than Flibe. Beryllium is used as a neutron multiplier in both concepts (with larger amount in the case of Flinabe) to improve the local TBR. The blanket in both concepts has a thickness of 65 cm in the OB (40 cm in IB), including a 5 cm-thick front Be zone (8 cm in case of Flinabe). The radial build in both blanket concepts was arrived at after several iterations to maximize the TBR while ensuring adequate radiation protection to the magnet and making the vacuum vessel a life-time component. The FW is estimated to last ~5 years before replacing the blanket. The results of this neutronics assessment are reported in a companion paper.

In This paper we present the results for assessing the radioactivity and decay heat for up to 1000 years after shutdown. This assessment is performed separately for the structural material, the Be multiplier and the breeder (Flibe/Flinabe). The average wall loading on the OB and IB is considered in the analysis and the modules in the poloidal direction are assumed to be ~8.3 m long. In estimating the pertaining parameters in the Flibe (or Flinabe) it is assumed that 1/4 of its volume is inside the reactor during operation with the rest flowing outside. The total activity and decay heat in the F82H structure is very similar in both concepts (~2000 MCi and ~10 MW, at shutdown, respectively). The total activity in the Flibe is slightly larger in the Flibe but the decay heat (dominated by Na-22 and Na-24) is much larger in the Flinabe by up to an order of magnitude in the time frame of 1 hour-10 years after shutdown. The dominant contributor to Flibe decay heat is F-18 up to ~1 day after shutdown. The Class C waste disposal rating (WDR) was estimated for each material using both Fetter and NRC limits. For Flibe, Flinabe and Be the WDR is much lower than unity. However, the WDR for F82H is ~0.6-1.3 (Fetter) and is dominated by Tc-99 and Nb-94. They are attributed to reactions with Mo and Nb present in F82H with levels of 70 wppm and 4 wppm, respectively. To ensure that F82H qualifies for shallow land burial, it is suggested to reduce these two impurities to ~50 and ~3 wppm, respectively. The results cited in this paper are needed to assess safety concerns such as thermal response during accident conditions and the mobilization of the radiological inventories and site boundary dose following these accidents.