Approaches for Minimizing Radioactive Tritium and ^{14}C in Advanced High Temperature Gas-Cooled Reactors

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Abstract : High temperature gas-cooled reactors (HTGRs) are considered as one of the next-generation advanced nuclear reactors, in which porous nuclear graphite is used as neutron moderators, reflectors, structure materials, and cooled by inert helium. Radioactive tritium and ^{14}C are generated in terms of reactions of thermal neutrons and ^{6}Li, ^{14}N, ^{10}B impurely within nuclear graphite and the coolant during HTGRs operation. Currently, hydrogen and nitrogen diffusion behavior together with nuclear graphite microstructure evolution were investigated to minimize the radioactive waste release, using thermogravimetric analysis, X-ray computed tomography, the BET and mercury standard porosimetry methods. It is found that the peak value of graphite weight loss emerged at 573-673 K owing to nitrogen diffusion from graphite pores to outside when the system was subjected to vacuum. Macropore volume became larger while porosity for mesopores was smaller with temperature ranging from ambient temperature to 1073 K, which was primarily induced by coalescence of the subscale pores. It is suggested that the porous nuclear graphite should be first subjected to vacuum at 573-673 K to minimize the nitrogen and the radioactive 14°C before operation in HTGRs. Then, results on hydrogen diffusion show that the diffusible hydrogen and tritium could permeate into the coolant with diffusion coefficients of $> 0.5 \times 10^{-4}$ $cm^2 \cdot s^{-1}$ at 50 bar. As a consequence, the freshly-generated diffusible tritium could release quickly to outside once formed, and an effective approach for minimizing the amount of radioactive tritium is to make the impurity contents extremely low in nuclear graphite and the coolant. Besides, both two- and three-dimensional observations indicate that macro and mesopore volume along with total porosity decreased with temperature at 50 bar on account of synergistic effects of applied compression strain, sharpened pore morphology, and non-uniform temperature distribution.

Keywords : advanced high temperature gas-cooled reactor, hydrogen and nitrogen diffusion, microstructure evolution, nuclear graphite, radioactive waste management
Conference Title : ICNRRM 2017 : International Conference on Nuclear, Radiochemical and Radiobiological Measurements
Conference Location : Copenhagen, Denmark
Conference Dates : June 11-12, 2017

Open Science Index, Nuclear and Quantum Engineering Vol:11, No:06, 2017 publications.waset.org/abstracts/70163.pdf