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論 文 内 容 の 要 旨
Abstract of Dissertation

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Plant Life Management (PLM) is important to ensure the safe of long-term operation (LTO) of Light Water Reactors (LWRs), in which non-replaceable components, such as Concrete Biological Shield (CBS), must maintain their integrity during normal operation and transient conditions, e.g., locally exposure to high temperature and irradiation flux. Recent studies indicated that two processes could affect the integrity of CBS: (1) radiation-induced volume expansion (RIVE) in concrete's aggregates due to the amorphization transition, and (2) the radiation-induced drying in cement paste due to radiation heating and/or exposure to elevated temperature from hot RPV (~300°C). Current attentions are related to the estimation of a reference level for concrete considering possible aging phenomena and establishing the inspection program for the existing concrete structure. Nevertheless, it is difficult to define appropriate reference level due to several issues: unknown mechanism of RIVE, diversity of concrete aggregates, and diversity of neutron spectrum and energy cut-off. The purpose of this study is to clarify environmental degradation effects and resultant changes in properties of concrete and its components considering the long-term operation (i.e., up to 60- or 80-year operation).

Ion irradiation was used to extract the RIVE mechanism on three common siliceous minerals in rock-forming aggregates including quartz, albite, and microcline. The main findings are (1) though both ionization and collision was found to contribute to RIVE, ionization is insignificant under neutron irradiation, thus RIVE is mainly indicated by knock-on displacements (i.e., displacement per atom, dpa), this suggests the use of the amount of knock-on displacements as an index of irradiation effects on concrete structures during LTO; (2) since the RIVE is currently correlated with the amorphization and RIVE is presumed to reach the saturation at amorphization, the present study showed the RIVE can continue even after the amorphization; (3) correlating the change of RIVE and mechanical properties under irradiation in three minerals showed that fluence dependence of RIVE was similar, but the mechanism of RIVE in the minerals differed, which is found to be related to mineral structure and alkali ion content; and (4) irradiation temperature was found to enhance the structural relaxation of amorphized silica with an activation energy around 0.13eV, this is found to be related to the enhanced mobility of defects.

Based on the above results, the current literature data on neutron-irradiated concrete was re-evaluated to determine a threshold value considering the RIVE effect. The current value was initially regarding neutron fluence which remains high uncertainty due to diversity of neutron spectrum, thus a correlation parameter was proposed and it can be used to normalize neutron fluence into the dpa. The RIVE is found to occur beyond 0.04dpa, but concrete decreases the strength at 0.02dpa. This could be related to radiation-induced drying effect.

The possibility of ultrasonic-based method has been examined on real concrete samples, which have been subjected to elevated temperatures to simulating the drying effects. The results showed a good correlation between ultrasonic parameters and Young's modulus. This suggests ultrasonic wave could be used to assess the condition of concrete structure during LTO.