JAEA Studies on High Burnup Fuel Behaviors during Reactivity-Initiated Accident and Loss-of-Coolant Accident

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The objectives of fuel safety research program at Japan Atomic Energy Agency (JAEA) are; to evaluate adequacy of present safety criteria and safety margins; to provide a database for future regulation on higher burnup UO_2 and MOX fuels, new cladding and pellets; and to provide reasonably mechanistic computer codes for regulatory application. The program aims also; to promote a better understanding of phenomena appearing in high burnup region and MOX, such as rim-effect and an effect of Pu agglomerates in MOX, and to evaluate those effects on fuel behavior in accident conditions; and to evaluate fuel behaviors with higher fuel duty, such as plant power up-rates, longer operating cycles and water chemistry changes. The JAEA program is comprised of; reactivity-initiated accident (RIA) studies including pulse-irradiation experiments in the NSRR, cladding mechanical tests, and development and verification of a computer code RANNS; loss-of-coolant accident (LOCA) tests including integral thermal shock test, oxidation rate measurement, and cladding mechanical tests; development and verification of a computer code FEMAXI-6 which simulates high burnup fuel behavior under normal operating and abnormal transient conditions; and studies on phenomena specific in high burnup region including thermal properties measurements, experimental and analytical simulation of rim structure formation, cladding mechanical tests on effects of hydrides, etc.

The RIA-simulating experiments are being actively performed by using a pulse-irradiation capability of the NSRR. Data obtained from the NSRR experiments regards with fuel failure, fission gas release and post-failure events. Since cladding failure in high burnup fuels due to pellet/cladding mechanical interaction (PCMI) has become a primary regulatory concern, the experiments have a particular importance to determine a threshold of cladding failure due to the PCMI in terms of fuel enthalpy increase. Tested fuels in the experiments are sampled from high burnup fuels irradiated in power-producing reactors. In addition to fuels irradiated in Japanese light-water reactors (LWRs), the program has obtained higher burnup UO_2 and MOX fuels irradiated in European PWRs and BWRs through a shipment from Europe to JAEA-Tokai in 2005. The fuels tested in the NSRR include UO_2 and MOX (MIMAS and SBR) fuels irradiated in PWRs, e.g. Vandellos-2, Spain, and BWRs, e.g. Beznau-1, Switzerland, and fuel burnup reaches 79 MWd/kg at a maximum case. Cladding materials of the tested fuels are Zry-2, Zry-4, MDA, NDA, ZIRLO and M5. Although most of these experiments have been performed with coolant conditions at a room temperature and atmospheric pressure, JAEA starts conducting tests at a high temperature/high pressure condition with a newly developed capsule. The first test with the capsule was successfully completed recently with a 67 MWd/kgU PWR fuel with M5 cladding.

A computer code RANNS is being developed in order to analyze fuel rod behaviors in RIA conditions, and is being verified with data from the NSRR experiments. The RANNS performs thermal and mechanical calculation for a single rod in axis-symmetric geometry and can address very rapid transient phenomena. The code has two types of mechanical model; one-dimensional deformation model for each axial segment length of rod, and newly-developed two-dimensional local deformation model for one pellet length. The pre-accident or End-of-Life conditions of the rod were predicted by the fuel performance code FEAMXI-6. The present targets of RANNS development are incorporation of a new stress-strain model of zirconium-based claddings which utilizes uni-axial tensile test data, and improvement of a two dimensional FEM mechanical model to predict a local deformation such as ridging of pellet during the PCMI. Analyses of PCMI by the two dimensional model were performed and verified with the data obtained in the recent high burnup PWR fuel experiments in the NSRR.

As for LOCA studies, a systematic research program on high burnup fuel behavior is being conducted. As a part of the program, integral thermal shock tests simulating the whole LOCA sequence were conducted with fuel claddings sampled from fuels irradiated in commercial PWRs in order to investigate behavior and condition of cladding fracture during quenching.

In addition to an overview of the fuel safety research at JAEA, most recent progresses in the RIA and LOCA tests programs and the codes development are described and discussed in the paper.