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Interaction of Hydrogen with Neutron Irradiation-Induced Nanoscale Defects in Irradiated Steel

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Abstract

It is known that in traditional power engineering hydrogen may be one of the first primary sources of equipment damage. This problem has high actuality for both nuclear and thermonuclear power engineering owing to interaction of hydrogen with such nascent under neutron and ion irradiation nanoscale structures as radiation defects and grain-boundary segregants.

Particularly reactor pressure vessels (RPV) of the WWER-440/230 project were manufactured without stainless cladding that is in contact with primary circuit water and accessible for hydrogen as a product of RPV wall corrosion. A structural cracking has been recognized as a technological challenge for maintenance of light water reactors in the stainless steel corrosion avoiding cladding of reactor pressure vessels. Therefore, in the case of cladding failure, the problem arises of hydrogen (as a corrosion product) embrittlement of irradiated steel because of exposure to the coolant.

Effects on steel/ hydrogen interactions (adsorption, desorption, diffused, mechanical properties at various charge levels, post-irradiation annealing) were investigated from neutron fluence and irradiation temperature. Experiments demonstrate that the higher the fluence of neutrons and the lower the temperature of the beam, the more hydrogen defects exist and the resulting effect on mechanical properties of RPV steel. Hydrogen concentration was determined by thermal degassing method at temperatures up to 1000°C with gas chromatograph (thermal conductivity detector) registration of gas released. It was determined at several experiments in I.V. The Institute for Kurchatov was several times more comparatively original with steel specimens irradiated at extremely low temperatures (100-140 ° C) in sealed ampoule packed with argon.

Analysis of the combined radiation-hydrogenation embrittlement of the 48TS type vessel steel was performed in where at the mention of the American and own data question concerning unknown source of hydrogen in metal that was irradiated in nuclear reactor in hermetic ampoules (was named as “irradiation-produced hydrogen” (IPH) was raised. Ageing of the irradiated steel during 48 hours revealed that IPH is not diffusible up to irradiation temperature attaining that is IRH are in the irradiation produced traps. Later data appear on unexpectedly high hydrogen concentrations in stainless steels irradiated in BWR type reactors and high generations of hydrogen and helium in nickel under irradiation. Then surprisingly elevated amounts of hydrogen in irradiated graphite were also detected.

In fact, in the forged rings of the reactor pressure vessels, the search for a huge hydrogen source is necessary in particular [8,9] in Belgium for the Doel 3 and Tihange 2 nuclear power plants. Electrabel proprietor thought that faults are hydrogen flocks “most definitely”. The spread of impurity elements like phosphorus is stimulated through radiation in this context, tin, antimony and so on with time may takes place and result in intergranular segregations on the former austenite grain boundaries Interaction of hydrogen- the inter-granular hydrogen embrittlement of reactor pressurized vessel compounds must be considered as potential cause. Recognition search was carried out to examine the effect of the hydrogenation of the model metal and of RPV steel. We attribute the deterioration of the metal properties to the particular intergranular breakup caused by hydrogen, in which hydrogen becomes one of its segregants over time. RPV ageing can severely reduce the mechanical properties of the steel.

As a potential initial theory of the mysterious hydrogen source, protons can be released during beta-decay of free neutrons, as the protons found of nuclear reactors are a testament to the beta-decay of free neutrons (lifetime roughly 15 minutes.).

Reactor pressure vessel (RPV) is the key structural component of the NPP that determines the lifetime of nuclear power plants. Environmentally induced cracking in the stainless steel corrosion-preventing cladding of RPV’s is one of the technical problems in the maintenance of light-water reactors. In the case of cladding failure, the problem arises of hydrogen (as a corrosion product) embrittlement of irradiated RPV steel because of exposure to the coolant. Effects of neutron fluence and irradiation temperature on steel-hydrogen interactions (were studied. Experiments clearly reveal that the higher the neutron fluence and the lower the irradiation temperature, the more hydrogen-radiation defects occur including defects stabilization by hydrogen. High susceptibility to hydrogen was observed at specimens which had been irradiated at relatively low temperature. However, the susceptibility decreases with increasing irradiation temperature and at operating temperature stabilized at the level close to hydrogen-free condition. However, this situation exists at early stages of RPV operation. Radiation-stimulated diffusion of the impurity elements such as phosphorus may take place and result in intergranular segregation. Therefore interaction hydrogen – grain-boundary segregants have to be taking into account as potential cause of the intergranular embrittlement of RPV materials. Grain-boundary segregants - hydrogen Interaction have to be taking into account as potential cause of the intergranular hydrogen-assisted embrittlement of RPV materials.

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