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ScienceDirect

Nuclear Energy and Technology 1 (2015) 68–73

www.elsevier.com/locate/nucet

Analysis of damaged welds no. 111 in the PGV-1000 steam generator and damage repair proposals

V.P. Povarov*

Novovoronezh NPP, a Branch Department of JSC "Rosenergoatom Concern". 396072, Novovoronezh, Voronezh Region, Yuzhnaya 1 industrial estate, Russia

Available online 28 February 2016

Abstract

Reliability of complex facilities, such as nuclear power plants, under construction or in operation is fundamental to the safety of humans and the natural environment. The key reliability-related factors are absence of errors in structural design and calculations, proper selection of materials and the manufacturing technology, quality of the materials used and the onsite welding operations, conditions of operation and in-service inspection.

Despite the fact that much attention is given in the course of the NPP design and operation to ensuring reliability, the experience of operation has demonstrated that there is a potential for crack formation in welded joint No. 111 of the PGV-1000 M steam generator. The crack nucleation and growth mechanism has not been yet unambiguously identified.

This paper presents the results of a study into the causes for the metal damage in the region of welded joint No. 111 between the hot header and the steam generator vessel's nozzle of Dn1200.

Keywords: Discontinuity; Steam generator (SG); Welded joint; Experimental research.

The reliability of the VVER-1000 NPP's main equipment, specifically in conditions of an extended service life, depends on the reliability of its individual components. The most critical item for theVVER-1000 steam generators (SG) is the welded joint between the primary coolant "hot" header and the steam generator vessel's Dn1200 nozzle (Fig. 1).

We shall consider the descriptions of recurring defects at nuclear power plants in Russia and Ukraine that manifest themselves as "cracks and discontinuities in the metal of welded joint No. 111 between the primary circuit header and the SG vessel" in the period of 1996 through 2013 (as of 2013) [1].

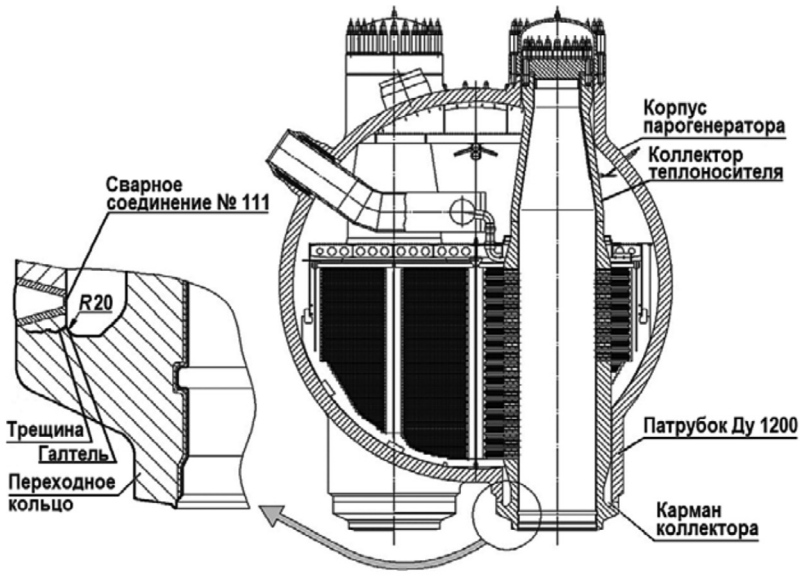
A through-the-thickness defect was detected in welded joint (WJ) No. 111 between the "hot" header and the SG allowance area at unit 1 of South-Ukrainian NPP during the 2001 preventive repair operations on SG-2. A non-through crack of the length 315 mm was detected at South-Ukrainian NPP's unit 2 during an ultrasonic (US) inspection of WJ 111 between the hot header and the SG-1 vessel, extending throughout the central portion of the Dn850 MCP bend. Inadmissible discontinuity flaws were detected in the WJ between the primary circuit "cold" header and the Dn1200 nozzle at unit 2 of Zaporozhye NPP during an US inspection of SG-2's WJ 111 in the course of the 2010 preventive repair operations. During a scheduled US inspection of WJ 77/1 in 1SG-3, using TsNIITMASh's methodology, in the period of the preventive maintenance at unit 1 of Kalinin NPP in 2006, discontinuity flaws of the length ~400 mm were detected along the WJ at a depth of up to 30 mm from the outer surface. An additional "manual" inspection of WJ 77/1's defective area proved that the discontinuity existed.

The presence of black loose deposition with a thickness up to 20 mm was detected at the defect point by a visual examination of the "cold" header "pocket". In the period of a medium repair at unit 2 of Balakovo NPP in 2006, a discontinuous chain of flaws was detected during a scheduled US inspection of the metal in 1SG-1's WJ, using TsNIITMASh's methodology, in the form of four areas of the length 20 to 30 mm each (total length ~470 mm) and of the width ~30 mm, extending along the WJ, at a depth of 45 to 50 mm from the outer surface. No inadmissible defects were detected during the inspection of the same joint by the Avgur 4.2 automated US inspection system. An additional "manual" US inspection of the defective area in SG-1'sWJ

* Corresponding author:
E-mail address: PovarovVP@nvnpp1.rosenergoatom.ru.

Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).

http://dx.doi.org/10.1016/j.nucet.2015.11.014



Сварное соединение № 111 = Welded joint 111
Корпус парогенератора = Steam generator vessel
Коллектор теплоносителя = Coolant header
Трещина = Crack
Галтель = Fillet
Переходное кольцо = Adapter ring
Патрубок Дн 1200 = Dn1200 nozzle
Карман коллектора = Headerpocket

Fig. 1. PGV-1000 M steam generator.

111-1 was conducted to update the US test results. It was confirmed that discontinuity flaws existed. After the measurement error was eliminated, another inspection was conducted using the Avgur 4.2 system based on the Avgur AUSI method. The inspection revealed discontinuity flaws of the size exceeding the permissible quality assessment standards under PNAE G-7-010-89.

A review into the experience of operation of Novovoronezh NPP's unit 5 shows that there were major damages around WJ 111 in all four SGs [2]. The defects are found in the radius blend between the pocket and the metal of WJ 111-1.

During the period of operation, defects were detected in WJs111-1 on the following SGs: 5SG-1 in 1998 and in 2004; 5SG-2 in 2007; 5SG-3 in 2001; 5SG-4 in 2007 and in 2009, and 5SG-1 in 2013. The unit was in a "hot" state at 10:20 am on 6 June 2013 with the outage program being under way as part of the 2013 preventive repair. A steam leak was detected during the equipment inspection from beneath the thermal insulation in the region of the "hot" header in the bottom part of 5SG-1's vessel. A 25 mm long crack with a through-the-thickness defect, having an angle of ~ 45° to the weld axis, was detected at 7:30 am on 08.07.2013 as the result of a visual and liquid penetrant examination. After the reactor was brought into a cold state and thermal insulation was removed, a leak was detected at 10:40 the same day near WJ 111 of 5SG-1's "hot" header.

The 5SG-1 steam generator was commissioned in September 1989. Its operating time to the defect detection was 24 years. The component was in repair in 1998 and 2005 and welding was used in areas of the length 575 and 285 mm respectively. The component was tested nondestructively as part of the 2012 preventive repair.

Crack-like discontinuity flaws in excess of the rejection level were revealed by a US inspection and an automated US inspection. The discontinuity flaws were located in the WJ area of 510 mm long.

Fig. 2 presents a graphic illustration of the recorded damages to the critical joint, namely the region of the SG hot header welding to the MCP nozzle (WJ 111). Rather long and high crack-like defects,including through-the-thickness defects, have been detected by now in nine SGs of the VVER-1000 NPPs.

As shown by the figure, the initial damage area is directed in all cases towards the MCP hot leg as seen from the short generatrix of the nozzle near the area with the greatest mechanical damage.

During the initial damage, the main crack is directed along the weld and has a great deal of crack kinking. Further defects of the same welds looked differently: there were five knife-like cracks along the nozzle axis (across the weld) on the side opposing the initial defect.

The defect of WJ 111 was caused by corrosion damage to the metal due to intensive corrosive processes resulting in the corrosion pit formation, the effects from heavy tensile loads in the fillet region, and the transcrystalline crack propagation in the