International Conference
Nuclear Energy for New Europe 2004
Portorož • Slovenia • September 6-9

port2004@ijs.si
www.drustvo-js.si/port2004
+386 1 588 5247, fax +386 1 561 2276
PORT2004, Nuclear Society of Slovenia, Jamova 39, SI-1000 Ljubljana, Slovenia

An Overview of Non Destructive Inspection Services in Nuclear Power Plants

Simon Farley
Westinghouse Electric Germany GmbH
Dudenstrasse 44, 68167 Mannheim, Germany
simon.farley@de.westinghouse.com

ABSTRACT

Worldwide nuclear power plants are obliged by international and local authorities to perform periodical inspection and maintenance of safety relevant components. Non-Destructive Testing (NDT) techniques such as eddy current, ultrasonic, visual, dye penetrant and radiographic testing have been used and continually developed to inspect a wide range of components and materials. Inspecting such components invariably poses an interesting challenge due to complex component geometries, radiation exposure and the material make-up of the component or its welds.

As a leader in services to the nuclear industry, Westinghouse has an immense knowledge and experience in inspecting and repairing primary circuit components such as steam generators, reactor vessels, core internals, primary coolant pumps and loops, fuel elements and many other components in hazardous environments. To fulfil the requirements posed by authorities and inspection standards, remotely operated manipulators and vehicles have been designed to bring a diverse variety of probes and cameras to the object of inspection. Each inspection process is tested and qualified by the relevant qualification body.

In some cases the results of an inspection may require further in depth analysis or even repair of part of the component. These added challenges have often been met by specifically designed and qualified processes such as for the repair of vessel head penetrations or the repair of vessel nozzle safe end welds.

This presentation will give a general overview of a range of inspection capabilities and give a few examples in which repair was successfully performed.

1 INTRODUCTION

Whether via the United States Nuclear Regulatory Commission (NRC) or the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU), the regulation authorities of all nuclear power producing countries require each nuclear power plant (NPP) to compile an effective in-service inspection (ISI) programme in order to guarantee the safe, reliable operation of systems and components important to safety [1]. The objectives of an in-service inspection programme are [2]:

1) to detect and evaluate defects that could result in a failure adverse to safety prior to the next in-service inspection;
2) to detect and evaluate defects that subsequently should receive enhanced in-service inspection;
3) to minimize plant cost arising from failures in plant systems and components;

4) to make the most effect use of available resources taking into account in-service inspection programme requirements, “as low as reasonably achievable” (ALARA) radiation criteria, and co-ordination with other required maintenance and operations activities.

Through the surveillance of industrial issues, such as the Alloy 600 problem, the regulation authorities may also recommend or demand that NPPs extend the scope of their ISI programmes to include inspections requiring ever increasing complexity and to seek solutions to mitigate the effects of the problem.

2 STANDARD INSPECTION SERVICES

Companies like Westinghouse have long since taken on this challenge to continually find new methods of inspection and repair. Solutions are provided to offer maximum benefit to the customer. For example, through the development of stand alone submarine systems that are able to perform the visual inspection of core internals or the ultrasonic inspection of baffle to former and barrel to former bolts without necessitating the use of the fuel handling bridge or the polar crane. Liberating vital components such as the bridge and crane provide NPP with more flexibility during outage planning, thus saving time and cost. Figure 1 shows the MIDAS IV Submersible Remotely Operated Vehicle (SROV) and a reactor vessel inspection manipulator, both designed to save critical outage time.

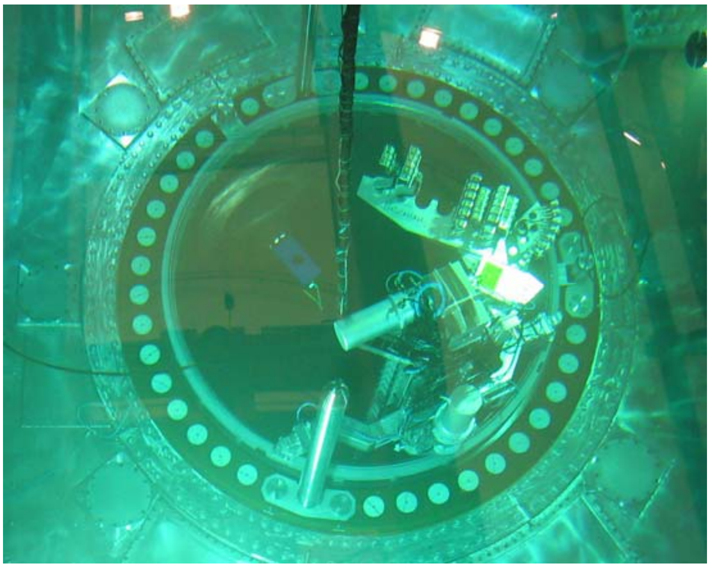

Figure 1: MIDAS IV Submarine and Inspection Manipulator in the Reactor Vessel

The Westinghouse fleet of SROVs has been developed to remotely visually inspect a great range of components such as the core internals, primary coolant loops and pumps, steam generator bowls and many more.

In particular since the introduction of new European ALARA limits in 2001, remotely operated probe manipulators and mechanised inspection and repair systems rise to the challenge of reducing personnel intervention time in high radiation areas to a minimum. § 2.1 and 2.2 give a couple of examples of the kind of standard inspections performed in NPPs.

2.1 Mechanised Primary Circuit Ultrasonic Inspection (UT)

As part of their ISI programme all nuclear plants are required to perform reproducible non-destructive inspections (in the form of x-ray, dye-pentrant, eddy current (ET) and ultrasonic testing) of piping systems, pressure vessels and other safety related components. Using a wide range of specialized manipulators Westinghouse regularly performs the mechanised ultrasonic inspection of the outer welds of steam generators, pressurizers, coolant pumps and piping systems. The manipulators are of versatile, modular form, enabling them to adapt to the geometry of the component being inspected and to remotely trace the area of inspection with specifically designed UT-probes. Figure 2 shows a manipulator remotely tracing the contour of a bend in the surgeline. The latest development in reactor vessel inspection, the SUPREEM manipulator, is depicted in Figure 3.

Figure 2: Ultrasonic inspection of surge line elbow

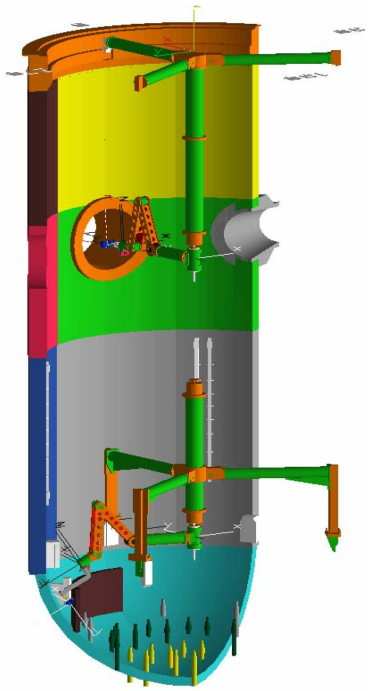

Figure 3: Reactor vessel inspection

2.2 Steam Generator Inspection

Tube integrity is integral to the safe operation of steam generators. Because of past problems with steam generator tubes affecting the operation of steam generators, the nuclear industry continues activities related to improving tube integrity [3]. The primary side of the tubes (from the inner surface) are periodically inspected using a range of ET probes and less frequently UT probes to detect cracks, loss of material (wastage & fretting) and changes in cross section (denting). Less frequently, a visual inspection of the inter tube area on the secondary side of the steam generator is performed, requiring miniature camera systems and endoscopes down to a size of 3 mm. Figure 4 shows some of the typical problems with steam generator tubes.

For many years Westinghouse has inspected and repaired steam generators on both the primary and secondary side. Many thousands of damaged tubes have been plugged to enable continued operation. Since plugging eliminates the active use of steam generator tubes the operating life of several steam generators has been extended by inserting and mechanically expanding removable PLUSS sleeves (PLUg replacing Sleeve which also Stabilizes) into the damaged steam generator tube, covering the defect like a Band Aid [4].

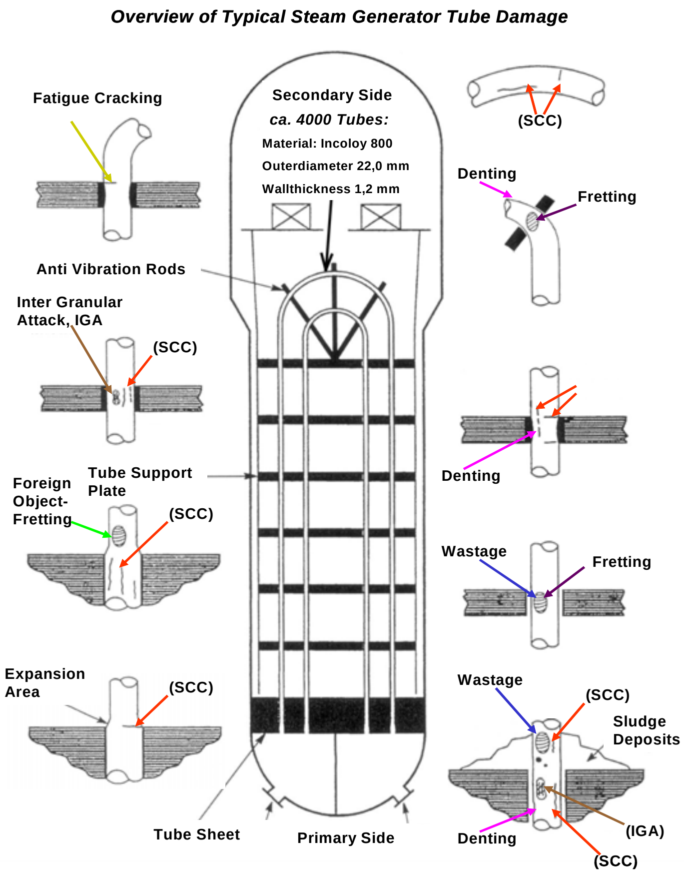

Figure 4: Typical damage to steam generator tubes

Several generations of remotely operated manipulators have been developed culminating in the ROSA inspection and repair arm and the recent light weight and quick to install PEGASYS manipulator, shown in Figure 5.

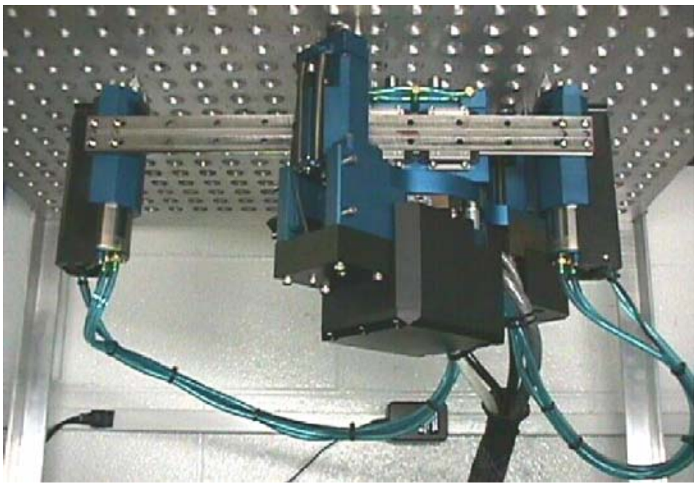

Figure 5.: PEGASYS Steam generator inspection manipulator

3 INDUSTRIAL ISSUES

As mentioned above the nuclear regulation authorities are continually observing issues and problems experienced throughout the nuclear industry and will, if necessary, demand that NPPs implement additional inspection plans or actions to mitigate or repair. A few examples are given below.

3.1 Alloy 600 Concerns

Alloy 600 is used to fabricate various parts in nuclear power plants, including reactor vessel head penetrations for control rod drive mechanism (CRDMs), in-core instruments (ICIs) and thermocouples, reactor vessel bottom mounted instrument (BMI) penetrations, pressurizer heater sleeves, and various other instrumentation ports. An overview is given in Figure 6. Related weld materials Alloy 82 and Alloy 182 are used to join these Alloy 600 parts to the ferritic steel components and also as a bi-metallic weld joining ferritic base materials to austenitic stainless steel base materials. Alloy 600 and its associated weld filler metals were originally used because of expectations of resistance to service-induced cracking. However, parts fabricated from these materials have demonstrated a susceptibility to primary water stress corrosion cracking (PWSCC) [5].

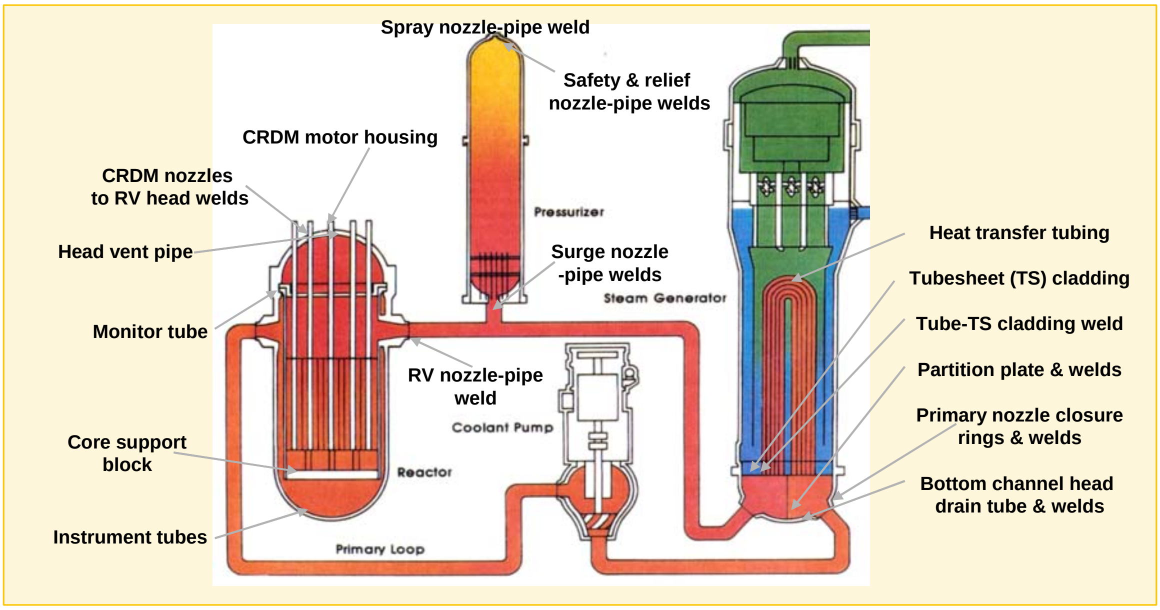

Figure 6: Alloy 600 Locations in Westinghouse Plants

In the United States, PWSCC of Alloy 600 first became an issue following a leakage event of a pressurizer heater sleeve nozzle at Calvert Cliffs Unit 2 in 1989.

The first indication of cracking in upper head Alloy 600 penetrations was identified in France at Bugey Unit 3 in 1991 during the ten-year primary system hydrostatic test. The leakage was from an axial flaw that had initiated on the nozzle inside surface near the elevation of the J-groove weld. Since that time all vessel head penetrations in France have been periodically inspected (every 3 years) and a campaign to replace all vessel heads is ongoing. In early 2001 four new leaks were identified in the U.S. plants Oconee 1, 2, 3 and ANO 1 as a result of cracking in the J-groove weld and vessel head penetration (VHP) nozzle. Thereby, the circumferential cracking for the first time found at Oconee 3 led to safety concerns by the

NRC. These findings resulted in an additional request by the NRC for inspections during the coming outages [6]. The most severe event was seen at the NPP Davis-Besse in March 2002. Significant wastage of the vessel head material resulted in a serious degradation of its structural integrity and the potential for a Loss of Reactor Coolant Accident (LOCA) [7].

The radial gap between the VHP nozzle and the thermal sleeve is usually only about 3 mm. To avoid having to remove the thermal sleeves to access the potentially cracked area, Westinghouse developed a range of slim sword like probes (gap probes) to inspect from the inner surface of VHP nozzles. These include a differential ET probe with two pancake coils used for crack detection and a TOFD (Time of Flight Defraction) UT probe for subsequent crack depth sizing. The recently developed Combo probe includes ET surface examination, TOFD UT volumetric examination and straight beam UT for leak path detection all in one probe (Figure 7). If deposits cover the surface, the surface can be cleaned before starting the inspection using specially developed sword type cleaning probes. In case the roughness or geometry of the surface (for example, if the penetration has been repaired) does not allow an ET inspection, Westinghouse has developed and qualified a gap probe to visually inspect the inner surface of penetrations equipped with thermal sleeve.

The Gap Scanner inspection tool, shown in Figure 8, is specifically designed to guide the range of gap probes into the annulus between the inner surface of the VHP nozzle and the thermal sleeve and to manipulate the probes so as to scan the surface area to be inspected.

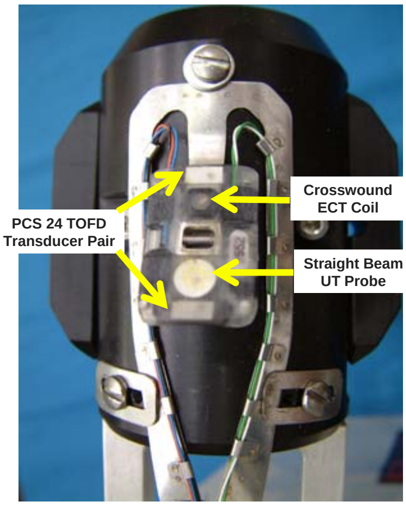

Figure 7 & 8: Combo probe & Gap scanner for Inspections of Penetrations with Thermal Sleeves

After finding over 200 pounds of boric acid crystals on the containment floor and protruding from the air boot around the "A" loop reactor coolant system hot leg pipe, examinations at V.C. Summer in October, 2000 showed a short through-wall axial crack in the hot leg nozzle safe end weld, approximately 3 feet from the reactor vessel. Additional examinations of the other 5 nozzle safe end welds found crack indications but no through-wall cracks. A 12-inch long section of the hot leg pipe containing the leaking weld was replaced with a new section of stainless steel pipe and Alloy 52/152 welds.

Several methods have been introduced to mitigate the problems arising from the Alloy 600 issue. The SAFEPLAY (Safe-End Protective Layer) is an inner diameter repair for Alloy 600 type butt-welded nozzle to safe-end welds, which applies a protective layer of Alloy 52M filler material, and has been successfully implemented at Ringhals 3 & 4 in Sweden. For butt weld joints the primary mitigation technique is to apply the Mechanical Stress Improvement Process (MSIP) which prevents or reduces stress corrosion cracking in piping by minimally contracting the pipe on one side of the weldment, replacing residual tensile stresses with compressive stresses. Zinc addition may accompany MSIP to allow the licensee to extend the inspection interval of welds. J-groove weld and penetration repairs can be made using a weld overlay embedded flaw repair technique that limits further growth and corrosion in the repair area (Figure 9). T-cold conversion, a method of improving the flow of coolant through holes in the upper internals lowers upper head temperature to reduce susceptibility to cracking.

Figure 9: Overlay of the vessel head penetration J-groove weld

3.2 Ultrasonic Inspection of Fuel Alignment Pins

Fuel alignment pins (FAP) in the upper and lower core internals ensure the exact radial positioning of the fuel assemblies. By the end of 1989 however, a total of 80 broken FAP's had been detected in several German PWR's. The problem was due to the pin material properties (Inconel X-750) and was restricted to individual pins. Operational experience has shown that materials with high contents of nickel are susceptible to intergranular attack / stress corrosion cracking). The German regulatory authorities consequently demanded that all FAP's made of Inconel X-750 be inspected and if necessary replaced.

An ultrasonic inspection method using an angle beam technique was developed. Probes with a detection sensitivity of less than 1 mm in depth were rotated 360° around the surface of the pin providing a complete volumetric examination from the collar to the threaded area of the pin. Figure 10 shows a schematic view of a FAP inspection.

Many FAP's of this type were subsequently replaced with a new improved Westinghouse design, which includes a central bore hole for improved ventilation. Although no further failures have been encountered the FAPs of some plants are still regularly inspected by passing a new UT probe variant through the centre of the FAP via the bore hole.

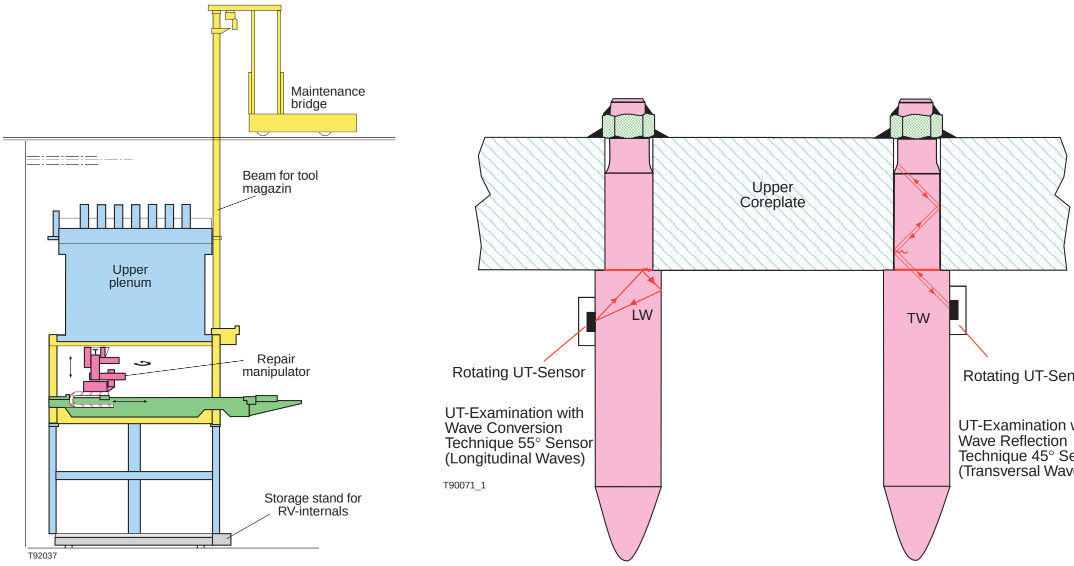

Figure 10: Schematic view of FAP inspection

3.3 Inspection of Rod Cluster Control Assemblies

During the operation of pressurized water reactors (PWR), flow induced vibration contact occurs between the control rods (CR) of a rod cluster control rod assembly (RCCA) and their guidance structure within the upper internals as well as at the top of the fuel assembly (FA). Such vibration contact can cause fretting wear at the affected cylindrical surfaces which leads to a reduction of wall thickness. A more important issue is the swelling caused to the CRs when they are in an area off high neutron flux. This may hinder the movement of the affected RCCA.

The facility used to inspect the control rods basically consists of a support plate carrying up to 6 eddy current inspection probes, through which the RCCA is passed (Fig. 11). The inspection plate is installed in the fuel elevator or on top of a free location in the fuel storage rack. Each probe is equipped with two encircling coils, which are operated in both absolute and differential mode: Absolute mode (together with an external reference probe) to determine loss of cross section due to wear marks and their axial extension; differential mode to detect defects such as cracking due to absorber swelling. In addition to the encircling coils, each probe carries up to 16 pancake coils, radially arranged to determine the circumferential profile of the control rod.

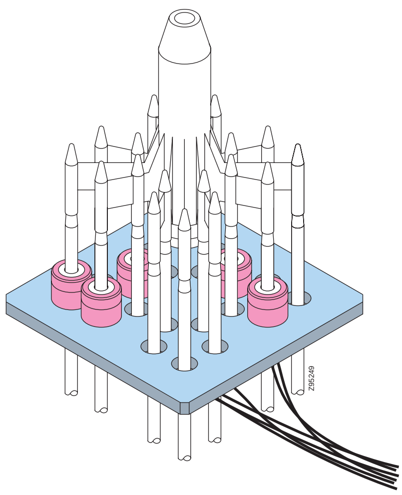

Figure: 11: RCCA passing through ET probes

4 CONCLUSION

In recent years discoveries such as the serious reactor vessel head degradation at Davis Besse have lead to a dramatic heightening of safety awareness throughout the nuclear industry. Due to the failure of some utilities in applying appropriate inspection programmes the in-service inspection of NPPs has gained in importance and ISI programmes have come under greater scrutiny by the authorities. In this new climate the development of new technologies and methods of in-service inspection are becoming ever more relevant in providing a safe nuclear future.

REFERENCES

[1] Nuclear Code “Kerntechnischer Ausschuss“, website “www.kta-gs.de“.

[2] “In-Service Inspection of Nuclear Power Plants**”**, Safety Series No. 50-P-2, IAEA Manual, 1991, pp. 3.

[3] Steam Generator Management Program, Electric Power Research Institute (EPRI), website www.epri.com.

[4] Abdullah Majumdar & Franz Pötz, “PLUSS Sleeve: Product Development, Installation and Operational Experiences”, Proc. 12th Pacific Basin Nuclear Conference, Seoul, Korea, 2000, pp. 295-316.

[5] Alloy 600 Cracking, Nuclear Issues Forum, website “www.nuclearissuesforum.org”.

[6] NRC Bulletin 2001-01, “Circumferential cracking of reactor pressure vessel head pentration nozzles”, United States Nuclear Regulatory Commission, Office of Nuclear Regulation, Washington, D. C. 20555-0001, August 3, 2001.

[7] NRC Bulletin 2002-01, “Reactor pressure vessel head degradation and reactor coolant pressure boundary integrity”, United States Nuclear Regulatory Commission, Office of Nuclear Regulation, Washington, D. C., March 18, 2002. See also the NRC homepage www.nrc.gov.