UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
OFFICE OF NEW REACTORS
WASHINGTON, D.C. 20555-0001

September 22, 2013

NRC INFORMATION NOTICE 2013-19: QUASI-LAMINAR INDICATIONS IN REACTOR PRESSURE VESSEL FORGINGS

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power reactor under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

All holders of and applicants for a power reactor early site permit, combined license, standard design certification, standard design approval, or manufacturing license under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of the identification of quasi-laminar indications at a European commercial nuclear power plant (NPP) during a nondestructive examination (NDE) performed in 2012 of the reactor pressure vessel (RPV) forgings using ultrasonic testing (UT). Recipients may review the information for applicability to their facilities and consider actions, as appropriate, to assess similar conditions. Suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

A 2012 NDE inspection of a European NPP using a new type of inservice inspection (ISI) was conducted for the first time and revealed a large number of anomalies or "indications" in two RPV beltline shell ring forgings. The licensee reported that 7,205 indications were identified in the beltline lower shell and 857 indications were identified in the beltline upper shell.
A subsequent NDE inspection of a second, similar European RPV revealed similar indications, but in a lesser quantity. All of the indications were embedded (not connected to the surface) and quasi-laminar (oriented primarily parallel to the inner and outer surfaces of the RPV). These indications are also not located in or near the welds joining the forgings. The licensee concluded that the quasi-laminar indications resulted from hydrogen flakes that formed at inclusions and became flattened when the ingot was forged into a ring shape. The licensee performed detailed fracture mechanics analyses, both deterministic and probabilistic, and supporting analyses to assess the impact of the quasi-laminar indications on the structural integrity of the RPV. The European regulator's analyses are provided in a summary report, "Doel 3 and Tihange 2 Reactor Pressure Vessels Final Evaluation Report," which is available online at http://www.fanc.fgov.be/GED/00000000/3400/3429.pdf and additionally has been retained for informational purposes (Agencywide Documents and Management System

(ADAMS) Accession No. ML13233A147). The NRC provided technical review to support the European regulator in the areas of metallurgy, fracture mechanics, and NDE. In May 2013, after extensive testing and evaluation, the European regulator determined that the two affected RPVs were deemed safe for continued operation and were granted permission to restart the two units. The units were restarted in June 2013

BACKGROUND

All U.S. RPVs with beltline forgings were fabricated to the requirements of Section III of the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code* (Code), which provides inspection and acceptance criteria for quasi-laminar indications. All U.S. RPV forgings currently in service had to satisfy the requirements of various editions of Section III of the ASME Code.

Quasi-laminar indications may form in forgings during the fabrication process when water vapor reacts with the molten steel at high temperatures to form hydrogen. Hydrogen is more soluble in molten steel than in solid steel. As the molten steel cools and solidifies, hydrogen comes out of solution and accumulates in molecular form at internal metallurgical defects such as inclusions and voids. The pressure of the gaseous hydrogen at these locations can be sufficient, in combination with internal stresses that occur during cooling, to form embedded cracks known as hydrogen flakes. These typically take the form of quasi-laminar indications. Hydrogen flaking occurs only during the fabrication process—flaking is not a service-induced phenomena. Forging fabricators have long known of this issue and have adopted procedures and practices to minimize occurrences of hydrogen flaking. More efficient degassing processes have been developed and applied over the years during steelmaking to reduce hydrogen levels in an ingot to minimize the potential for hydrogen flaking. These degassing procedures were well-established by the time the first generation commercial NPPs were being manufactured in the 1960s and were used for all NPPs. The degassing procedures were required by the materials specifications and were performed on the molten material before it was formed into an ingot. In rare cases, degassing may not prevent hydrogen flaking.

The American Society for Testing and Materials (ASTM) material specification and ASME Code, Section III both require UT examination of RPVs. A surface examination using magnetic particle testing (MT) is required by ASTM after final machining. In addition, Section XI of the ASME Code requires preservice, as well as periodic, examination (ISI examinations) of RPV welds after they enter into operation. The UT conducted during ISI examinations of RPVs in accordance with the ASME Code, Section XI, would not be expected to detect quasi-laminar indications of the type detected in the foreign RPV because the ISI examinations required by the ASME Code are limited to the RPV welds and a narrow band of the forging material adjacent to the weld.

DISCUSSION

U.S. plants have either forged shells or welded plates in the beltline region of the RPV. Many RPVs also have forgings for the nozzle shells and closure heads, even if the beltline region shells are composed of welded plate materials. The RPV forgings in the United States are either A508 Class 2 or A508 Class 3 steel. The manufacturers for the major shell components were Rotterdamsche Droogdok Maatschappij/Rotterdam Nuclear (Rotterdam Dockyard),

Babcock & Wilcox, Chicago Bridge and Iron, Combustion Engineering, Societe Creusot, and Hitachi. The large forgings were supplied by one of five manufacturers: Bethlehem Steel, Creusot-Loire, Japan Steel Works, Ladish, or Rotterdam Dockyard. While the forgings in the European NPP were manufactured by Rotterdam Dockyard (using ingots supplied by Friedrich Krupp Hüttenwerke (Krupp)), there is no evidence of any factors unique to the forging practices of the Rotterdam Dockyard, or the practices used by Krupp in making the ingots, which suggest an increase in the likelihood of developing quasi-laminar indications during the fabrication process in comparison to other forging manufacturers.

Since the 1950s, vacuum degassing, which minimizes hydrogen in the environment during the manufacturing of forgings, has been a standard practice applied by all heavy-section steel forging manufacturers. De-hydrogenation heat treatments and cooling practices to minimize hydrogen were also common practices applied by manufacturers of nuclear RPVs.

ASME Code, Section III, requires the UT examination of all forgings during the fabrication process and specifies the acceptance criteria. Per Section III, a forging is considered to be unacceptable if the UT examination detects the presence of reflectors that produced indications resulting from discontinuities in the material accompanied by a complete loss of back reflection from the far side of the structure. The applicable Codes required that the examinations be performed in accordance with ASTM SA-388; this document defines the recording criteria implemented for the RPV forging examinations. Licensees are required to maintain all fabrication records, including NDE and acceptance records; therefore, licensees should have records of the NDE performed on RPV forgings during fabrication. If recordable quasi-laminar indications were detected during the fabrication of any RPV, Section III of the ASME Code would require the indications to be compared to the examination acceptance criteria. Unacceptable indications would require repair in accordance with the ASME Code, Section III.

CONTACT

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

/RA/ (Sher Bahadur Acting for)

Lawrence E. Kokajko, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA/

Michael C. Cheok, Acting Director
Division of Constructions Inspection
and Operational Programs
Office of New Reactors

Technical Contacts: Robert Hardies, NRR
301-415-5802
E-mail: Robert.Hardies@nrc.gov

Carolyn Fairbanks, NRR
301-415-6719
E-Mail: Carolyn.Fairbanks@nrc.gov

Gary Stevens, RES
301-251-7569
E-mail: Gary.Stevens@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under NRC Library/Document Collections.

CONTACT

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

/RA/ (Sher Bahadur Acting for)

Lawrence E. Kokajko, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA/

Michael C. Cheok, Acting Director
Division of Constructions Inspection
and Operational Programs
Office of New Reactors

Technical Contacts: Robert Hardies, NRR
301-415-5802
E-mail: Robert.Hardies@nrc.gov

Carolyn Fairbanks, NRR
301-415-6719
E-Mail: Carolyn.Fairbanks@nrc.gov

Gary Stevens, RES
301-251-7569
E-mail: Gary.Stevens@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under NRC Library/Document Collections.

ADAMS Accession No.: ML13242A263; *concurred via e-mail **TAC NO. MF0921**

OFFICE	NRR/DE/EVIB	Tech Editor*	NRR/DE/EVIB	NRR/DE
NAME	CFairbanks	KAzariah-Kribbs*	SRosenberg	PHiland
DATE	08/28/13	07/17/13	09/03/13	09/04/13
OFFICE	OIP/IP/ICAB*	NRR/DPR/PGCB	NRR/DPR/PGCB*	NRR/DPR/PGCB
NAME	SDembek	MBanic	CHawes	(TAlexion for) SStuchell
DATE	09/06/13	09/06/13	09/11/13	09/13/13
OFFICE	NRO/DE/CIB*	NRO/DCIP	NRR/DPR	NRR/DPR
NAME	DTerao	MCheok	SBahadur	***/SBahadur for/*** LKokajko
OFFICE	09/06/13	09/17/13	09/ 19 /13	09/ 22 /13

OFFICIAL RECORD COPY