Fire Protection System: Aging management of buried gray cast iron piping and piping components revised

Dominion Letter Serial Number 21-213 dated July 29, 2021 (ML21210A396) provided a revision to the aging management of fire protection system buried gray cast iron piping and piping components. As detailed in the supplemental letter, consistent with the requirements of NUREG-2191 Section XI.M41, Buried and Underground Piping and Tanks program, and NUREG-2191 Section XI.M33, Selective Leaching program, periodic and opportunistic inspections would be conducted for buried gray cast iron fire protection piping and piping components. A minimum of six excavations will be conducted at each unit and five of the inspections at each unit will destructively examine the buried gray cast iron fire protection piping to inspect for the loss of material due to selective leaching. Consistent with the requirements of NUREG-2191 Section XI.M41, Buried and Underground Piping and Tanks program, a ten-foot pipe length will be excavated for each buried gray cast iron fire protection piping sample. The periodic inspections will be conducted in the 10-year period prior to the subsequent period of extended operation (SPEO) and periodically in each 10-year period during the SPEO. The removed piping will be replaced with ductile iron material.

In addition to the actions described above for loss of material due to selective leaching, this supplement revises the SLRA to also require inspections of buried gray cast iron fire protection piping for detection and evaluation of cracking due to cyclic loading. Specifically, Visual (VT), magnetic particle (MT), and radiographic (RT) nondestructive examination (NDE) methods will be used on the excavated gray cast iron fire protection piping to inspect for cracking due to cyclic loading. The NDE examination results will be evaluated by a Level II or III examiner qualified in accordance with ASME Code, Section XI requirements to identify the presence of cracking. If cracking is not identified using the NDE techniques, described below, then a one-foot axial piece of the fire protection piping will still be destructively examined for the loss of material due to selective leaching as required by NUREG-2191 Section XI.M33, Selective Leaching program. If cracking is identified, then a one-foot axial piece of fire protection piping will be selected for further examination for cracking due to cyclic loading and the loss of material due to selective leaching using destructive examination methods. The one-foot axial piece of fire protection piping will be selected from a bounding location based on the crack size and characterization provided by the NDE techniques.

The NDE techniques and methods that will be used to identify potential crack locations, the methodology used for determining the bounding location, and the techniques that will be used during the destructive examination are provided below. If a crack is determined to be the result of a manufacturing flaw, and not the result of aging, then the results will be documented in a metallurgical analysis report with no further actions required. If the crack is determined to be the result of cyclic loading, then a crack growth evaluation and flaw stability evaluation will be performed based on the predicted crack lengths at the end of the SPEO. If results of the evaluations indicate the depth or extent of cracking of the base metal is projected to cause loss of intended function prior to the end of the SPEO, Engineering will perform an evaluation to determine the extent of condition, extent of cause, and the need for further follow-on actions (e.g., additional inspections).

Nondestructive Examination Methods and Methodology

Visual (VT), magnetic particle (MT), and radiographic (RT) nondestructive examination (NDE) methods will be applied to assess the inside surface condition of the excavated gray cast iron fire protection piping. The NDE procedures and techniques applied for these examinations will be demonstrated and qualified in accordance with ASME Section 5, Article 2 for RT, Article 7 for MT, and Article 9 for VT. The NDE examination results will be evaluated by Level II or III examiners qualified in accordance with the requirements of ASME Code, Section XI.

A VT examination of the cementitious lining will be performed to identify and record any areas of lining damage that may be an indicator of degradation to the internal surface of the pipe. A MT examination of the inside diameter surface of the removed piping will be performed to detect indications of surface cracking. Particular attention will be applied to VT identified areas of lining damage during the MT examination. Linear surface indications representing potential cracking, identified with the MT method, will be validated using RT examination techniques.

To perform the MT examination method, access to the inside surface must be available. This will be accomplished by cutting the removed section of fire protection pipe in half along the length. The removed pipe may be cut to lengths that can safely be handled during the examination process. The cementitious lining will be removed, and the surface prepped to an acceptable condition to perform the MT examination. The lining removal and surface preparation techniques will ensure no detrimental impact on the final surface condition for the NDE being performed.

The MT examination method will be used to detect indications of cracks on the inside surfaces of the piping. The sensitivity is greatest for surface discontinuities and diminishes with increasing depth of discontinuities below the surface. The particle patterns are used to characterize the type and orientation of discontinuity that is detected. The maximum sensitivity will be to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting both axial and circumferential oriented flaws, each area will be examined at least twice, with the lines of flux oriented approximately perpendicular during each of the two examinations. The MT method is sensitive to surface discontinuities as well as other surface imperfections that may not be associated with cracking indications. For this reason, RT will be applied to validate potential crack indications detected with MT. The location, size and orientation of relevant linear indications detected will be recorded for further evaluation with RT.

The RT examination method will be applied to areas that have potential surface cracking identified using the MT method. A single wall technique, with the radiation passing through only one wall, will be able to be applied along with single wall viewing to maximize sensitivity. The RT examination technique provides a full volume examination of the pipe wall. Internal fabrication discontinuities may be detected during this examination, but the indication interpretation will focus on linear planar type flaws, which would eliminate manufacturing defects that have different characteristics. The use of image quality indicators (IQI) will be used to ensure proper image quality is provided for interpretation. Areas identified as containing potential inside surface cracking indications will be recorded and the bounding crack location selected for further metallurgical analysis.

Metallurgical Analysis – Destructive Examination

Confirmation of cracking in removed sections of gray cast iron fire protection piping can be performed using either metallography, fractography, or a combination of both. The process used will be dependent on the size of the crack detected by NDE results. The larger the crack, the more material that will be available for examination and thus there will be more flexibility in which method can be employed.

Metallography is used to examine the crystalline structure of metals. Samples prepared for metallography are cut and mounted in such a manner to not alter the material's condition, and then polished to a 1 micron or lesser finish. The prepared sample can then be examined under a light microscope as polished (unetched) or it can be etched in a particular reagent to expose the various constituents and phases of the metal.

Fractography involves the microscopic examination of fractured sections of materials. The microscopes are stereo light microscopes for low magnification work and a scanning electron microscope for higher magnification inspection. The fracture modes are documented as either transgranular, intergranular, overload (shear or tensile), or a combination of the three.

The bounding crack detected by NDE will be cut out in the materials laboratory in such a manner that the flaw is not disturbed and the microstructure of the material is not altered. Once the section containing the crack is removed, the typical method for examination, assuming a crack is of sufficient length, would be to cut off one end of the crack for metallography, and then section the pieces so that the remainder of the crack can be opened in the laboratory to expose the crack faces. Fractographic examination will then be performed on the open crack faces, while metallography will be carried out on the crack tip section. In most linear cracks, the center of the crack will represent the oldest portion, while the edges will account for the most recently formed part of the advancing crack front. The metallography performed on the crack edge will assess how the crack was advancing at the time of detection while opening up the remainder of the crack to allow for visual and microscopic inspection will provide confirmation as to the mode of crack advancement, and may provide qualitative information on the age of the fracture based on the amount of oxidation along the surface of the opened crack.

Both the metallography and fractography testing will indicate if corrosion was involved in the crack initiation process. Previous laboratory work performed on cast iron fractures has also employed microanalytical testing in the form of energy dispersive spectroscopy. This method allows deposits on the fracture surfaces of an opened crack to be analyzed for elemental composition. In doing so, if cementitious residues are detected along the portions of the fracture, this may indicate that the flaw in the pipe predated installation of the application of the cement lining and was therefore a flaw associated with fabrication of the pipe and not the result of aging.

Cracking in gray cast iron will display some fractographic indications typically associated with that type of cracking in all metals but will also display features unique to cast iron based on its structure and properties. Typically, when cracking is due to high cycle fatigue, the oldest portion of the crack is worn from repetitive crack opening and closings, and may, depending on the environment, be oxidized. The latter is especially true for cast irons because of their propensity to corrode in moist environments. Some fatigue features such as striations will most likely not be identified on fractures of gray cast irons because of the diverse microstructure and the low amount of ductility in the material that will not allow blunting of the advancing crack tip. Most of the fracture will consist of cleavage forming along the graphite flakes. Some ductility in the form of micro-voids may be visible in the ferrite and/or pearlite matrix if the material is subject to high stress conditions.

A crack due to cyclic loading captured in a metallographic cross section may exhibit a distinct pattern of crack advancement because of the material's unique microstructure. Gray cast irons have a crystalline structure that should consist of graphite flakes in a matrix of pearlite or ferrite. These graphite flakes are responsible for the material having a relatively low fracture toughness or "brittle-like" behavior. Cracks due to cyclic loading propagating through gray cast iron typically follow the path of least resistance and advance along a plane that will intersect many of the graphite flakes.

Cracks identified by NDE, as described above, will be further interrogated by destructive examination to establish cause. If the cracking is determined to a be due to cyclic loading through the destructive examination evaluation, then a crack growth evaluation and flaw stability evaluation will be performed based on the predicted crack lengths at the end of the SPEO. If results of the evaluations indicate the depth or extent of cracking of the base metal is projected to cause loss of intended function prior to the end of the SPEO, Engineering will perform an evaluation to determine the extent of condition, extent of cause, and the need for further follow-on actions (e.g., additional inspections).

Dominion Energy is an active participant in industry working groups that are investigating new and improved NDE techniques. As NDE technology evolves, Dominion will continue to monitor any relevant improvements, particularly those related to examination of cast iron, for potential incorporation into Dominion Fleet procedures.

Based on the above, SLRA Sections B2.1.27 and Table A4.0-1 Item 27 are supplemented, as shown in Enclosure 2.

SLRA B2.1.27, Buried and Underground Piping and Tanks - New Enhancement 6

6. Procedures will be revised to require a minimum of six excavations of buried gray cast iron fire protection piping be conducted at each unit and five of the excavated samples at each unit inspected internally for cracking due to cyclic loading. The inspections will be conducted in the 10-year period prior to the subsequent period of extended operation and in each 10-year period during the subsequent period of extended operation as follows:
    1. A ten-foot pipe length will be excavated for each buried gray cast iron fire protection piping inspection.
    2. Visual (VT), magnetic particle (MT), and radiographic (RT) nondestructive examination (NDE) methods will be applied to evaluate the buried gray cast iron fire protection piping sample for cracking due to cyclic loading.
    3. The examination results will be evaluated by a Level II or III examiner qualified to ASME Code, Section XI and the following performed, as applicable:
        - If there is no cracking identified using the NDE techniques then a one-foot axial piece of the fire protection piping sample will still be removed and destructively examined for

the loss of material due to selective leaching as required by NUREG-2191 Section XI.M33, Selective Leaching program (see Enhancement 5).

- If cracking is identified, then a bounding one-foot axial section of the fire protection piping sample will be selected based on the crack size and characterization determined by a qualified NDE Level II or III examiner and further destructive examination conducted to identify cracking due to cyclic loading. The destructive examination of the one-foot axial section will also be inspected for the loss of material due to selective leaching (see Enhancement 5).

4. If the destructive examination determines cracking is due to cyclic loading, then Engineering will perform a crack growth evaluation and a flaw stability evaluation based on the predicted crack lengths at the end of the subsequent period of extended operation.

5. If results of the evaluations indicate the depth or extent of cracking due to cyclic loading of the base metal is projected to cause a loss of intended function prior to the end of the subsequent period of extended operation, Engineering will perform an evaluation to determine the extent of condition, extent of cause, and the need for further follow-on actions (e.g., additional inspections).