May 11, 2015

MEMORANDUM TO: Alexander Adams, Jr., Chief
Research and Test Reactors Licensing Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

FROM: Cindy Montgomery, Project Manager ***/RA/***
Research and Test Reactors Licensing Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

SUBJECT: RESEARCH AND TEST REACTORS POOL WATER – SAFETY EVALUATION ON ELECTROLYTIC CONDUCTIVITY (TAC NO. ME8511)

In conjunction with the project to revise NUREG-1537, "Guidance for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," the staff of the Research and Test Reactors Licensing Branch (PRLB) has made a determination regarding electrolytic conductivity for pool water for research and test reactors. Specifically, the PRLB staff has determined that the license condition on pH for pool water for research and test reactors can be eliminated if electrolytic conductivity is controlled. The PRLB staff has ascertained a value of conductivity, which if licensees maintain their pool water below this value, the pH will be inherently kept within a range that would protect structures in the pool from corrosion. The maximum allowable value of conductivity is different for open and closed pools. This determination forms the technical basis for modifying NUREG-1537 guidance.

The staff of the Steam Generator Tube Integrity and Chemical Engineering Branch has reviewed the determination of the maximum electrolytic conductivity for open pool light water and has no objections. The PRLB staff's safety evaluation is enclosed.

Enclosure:
Safety Evaluation

CONTACT: Cindy Montgomery, NRR/DPR
301-415-3398

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SAFETY EVALUATION INPUT BY THE OFFICE OF NUCLEAR REACTOR REGULATION RESEARCH AND TEST REACTORS POOL WATER – SAFETY EVALUATION ON ELECTROLYTIC CONDUCTIVITY (TAC NO. ME8511)

1.0 INTRODUCTION

In conjunction with the project to revise NUREG-1537, "Guidance for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," the staff of the Research and Test Reactors Licensing Branch (PRLB) has made a determination regarding electrolytic conductivity for pool water for research and test reactors. Specifically, the PRLB staff has determined that the license condition on pH for pool water for research and test reactors can be eliminated if electrolytic conductivity is controlled. The PRLB staff has ascertained a value of conductivity, which if licensees maintain their pool water below this value, the pH will be inherently kept within a range that would protect structures in the pool from corrosion. The maximum allowable value of conductivity is different for open pools and closed systems not open to air.
This determination forms the technical basis for modifying NUREG-1537 guidance. A discussion on heavy water is included.

The staff of the Steam Generator Tube Integrity and Chemical Engineering Branch has reviewed and concurred on the determination of the PRLB staff on the maximum electrolytic conductivity for open pool light water research and test reactors.

2.0 EVALUATION

Guidance in NUREG-1537 states that most licensed research and test reactors contain solid fuel elements immersed in the primary coolant water. Experience has shown that the metal is susceptible to corrosion if the chemical purity of the water is not high. The water purity must be above the usual purity of the potable water supply to prevent oxidation and corrosion. Experience has shown that oxide buildup on aluminum-clad fuel operating at high power densities can reduce heat transfer.

Most corrosion processes involving aluminum-clad fuels and components are electrochemical; aluminum is passivated and protected by its oxide film in the pH range of 4 – 8.5. Stainless steel (used for cladding in some fuel elements) bathed in high purity water does not corrode.

To delay or prevent aluminum and stainless steel component failure by corrosion, non-power reactors should have a primary coolant cleanup system. The purity of the primary coolant should be maintained as high as reasonably possible for the following reasons:

- to limit the chemical corrosion of fuel cladding, control and safety rod cladding, reactor vessel or pool, and other essential components in the primary coolant system
- to limit the concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation
- to maintain high transparency of the water for observation of submerged operational and utilization components

ENCLOSURE

Experience at research and test reactors has shown that with a well-planned water cleanup system and good housekeeping practices, primary coolant quality can be maintained within the following ranges: electrical conductivity less than or equal to 5 micromhos/cm and pH between 5.5 and 7.5. According to NUREG-1537, maintaining pH between 5.5 and 7.5 will minimize corrosion of aluminum in open pool water research reactors.

NUREG-1537, Section 5.4, "Primary Coolant Cleanup System" provides the conditions for maintaining open pool water using measurement parameters that will protect aluminum components in the pool. The current guidance suggests that open pools maintain conductivity below 5 micromhos/cm *and* maintain pH between 5.5 and 7.5. However, there is a relationship between these two measurement parameters, whereby the physicochemical parameter, conductivity, may be relied upon, solely, to characterize water quality. In fact, the measurement of pH in high purity water is not required by the International Standard Organization (ISO), American Society for Testing and Materials (ASTM), nor United States Pharmacopeial (USP) standards due to the relative absence of ions that would enable electron transport between the measuring and reference electrodes of the pH electrode, resulting in errant and/or meaningless pH readings.

The pH of the highest purity water (0.055 microSiemens/cm) is inherently 6.998 at 25 degrees Celcius. However, in an open reactor pool with high purity water, with ambient carbon dioxide from the atmosphere, the dissolution of carbon dioxide in water, CO_2 (gas) $\leftrightarrow$ CO_2 (aqueous), ultimately leads to a pH of 5.6 – 5.8 and a conductivity minimum of approximately 1.1 micromhos/cm. Ambient atmosphere is comprised of approximately 400 ppm or 400 micromoles carbon dioxide per mole of air. This is equivalent to a mass concentration of 0.601 mg carbon dioxide per kg water. Atmospheric carbon dioxide equilibrates into open pool water and depresses the pH from approximately 7 to approximately 5.7.

The U. S. Nuclear Regulatory Commission (NRC) staff reviewed ISO International Standard 3696, ASTM standard D-5464, USP <645>, ANSI/ANS15.1, and a number of journal/symposium articles. The United States Pharmacopeia Convention, Physical Test <645> Water Conductivity, provides the physically possible values for pH and conductivity, given the relationship between the two parameters, at 25 degrees Celsius. USP <645> assumes that H_2CO_3 is constant and that total CO_2 increases with pH; and considers NH^{4+} and CO_3^{2-} equilibria together, all of which are realistic assumptions/considerations for research reactor open pools. The staff determined that the inherent relationship between pH and electrolytic conductivity negates the need for pH measurement, if conductivity is maintained at or below 5 micromhos/cm in open pool light water research reactors.

Closed systems do not have the same equilibrating effect of carbon dioxide. In open pools, the carbonic acid stabilizes pH to equilibrate at lower pH values. The relationship between pH and conductivity is different for closed pools; specifically, a narrower range of conductivity is necessary to maintain pH at acceptable levels. For closed pool water, conductivity would have to be maintained at or below 0.1 micromhos/cm to keep pH between 5.5 and 7.5.

Conductivity and pD values for very pure heavy water (deuterium) and the relationship between the two properties are not markedly different from conductivity and pH values for very pure light water. At 25^{o} C, in a perfectly closed system, not exposed to the atmosphere, the pH of H_20 is 7.0 (neutral for H_20), and the pD of D_2O (heavy water) is 7.45 (neutral for D_2O). However,

research and test reactors using heavy water experience small but measureable effects on pD through unavoidable exposure to atmospheric carbon dioxide. Exposure to this small amount of atmospheric carbon dioxide depresses pD for heavy water, and lowers pD to values which protect the aluminum and stainless steel structures within the tank, between of 5.5 and 7.5.

3.0 CONCLUSIONS

The PRLB staff has reviewed the available testing, analysis, and operating experience and has concluded that sufficient evidence exists concerning the relationship between conductivity and pH to modify the guidance set forth in NUREG-1537. Evidence justifies modifying the guidance such that open pools need not have a requirement for a pH technical specification *if* a technical specification and related surveillance requirement require that conductivity be kept at 5 micromhos/cm or below. Similarly, evidence justifies that closed pools need not require a pH specification *if* a technical specification and related surveillance requirement require that conductivity be kept at 0.1 micromhos/cm or below. Closed-system research and test reactors utilizing heavy water should follow the guidance for closed water light water systems. The assumptions leading to these conclusions are appropriate and consistent with the methods accepted by the PRLB staff for the acceptance of conductivity as a bounding measurement for pH for open research reactor pools. The PRLB staff has verified that a TS requirement for bulk (open) pool water conductivity measurement maximum of 5.0 micromhos/cm will ensure that the pH will, by its relationship to conductivity, stay between 5.6 and 5.8. The PRLB staff finds that the maximum conductivity of 5.0 micromhos/cm will maintain the pH in a range that will protect the reactor components in open pools. The PRLB staff has verified that a TS requirement for closed system conductivity measurement of a maximum of 0.1 micromhos/cm will ensure that the pH will, by its relationship to conductivity, stay between 5.6 and 5.8. The PRLB staff finds that the maximum conductivity of 0.1 micromhos/cm will maintain the pH in a range that will protect the reactor components in closed systems.