Extended Storage Considerations for Dry Cask Storage Systems Using Welded Stainless Steel Canisters-17436

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ABSTRACT

Dry storage of used nuclear fuel is likely to continue for several decades due to the lack of a permanent repository. The Electric Power Research Institute (EPRI) conducted a Failure Modes and Effects Analysis (FMEA) in order to identify degradation mechanisms that are relevant to Dry Cask Storage Systems (DCSSs) which store used fuel within a welded stainless steel canister housed inside a vented concrete cask. Chloride-Induced Stress Corrosion Cracking (CISCC) was identified as the potential degradation mechanism that would be most likely to challenge the confinement function of these canisters. This paper describes research efforts aimed at identifying canisters with CISCC prior to loss of confinement and understanding the consequences should such a loss occur. Key areas of research include development of aging management guidance with recommendations for the scope, frequency, and coverage for canister inspections, demonstration of non-destructive evaluation capabilities, and evaluation of the potential consequences in terms of dose to site personnel and the general public should cracking develop and grow through a canister wall.

INTRODUCTION

Operational licenses are nearing expiration at many of the independent spent fuel storage installations (ISFSIs) that are currently storing used nuclear fuel. The NRC is expecting 10 license renewal applications from 2017 to 2020, including renewals of 6 general design certificates of conformance which combined cover over 35 individual sites. [1] As is the case for operating reactor license renewal, ISFSI license renewal requires the licensee to consider potential degradation mechanisms that may occur during the period of extended operation and develop aging management programs to address them.

CISCC of the stainless steel canister housing used fuel has been identified as a potential degradation that would be most likely to challenge the confinement function of dry cask storage systems at ISFSIs. [2,3,4] It is important to note that while dry storage canisters may have the potential for CISCC based on the susceptible stainless steel materials used, the fabrication welding residual stress present, and the exposure to environments which can include salt particulates and humidity; there has not been confirmation that CISCC has occurred in any currently stored canister.

EPRI has developed CISCC aging management guidance for ISFSI managers to use in preparing site specific aging management programs. The technical basis for EPRI's guidance includes the FMEA along with literature survey results, deterministic flaw growth and tolerance calculations, susceptibility assessments, and probabilistic canister confinement integrity assessments. [3,4,5,6] The EPRI guidance provides an initial starting point for planning inspections of a sample of the overall canister population, with an understanding that additional inspection would be needed if CISCC is confirmed. Aging management programs are expected to be modified as new information becomes available, including inspection outcomes and results from on-going crack initiation and growth testing. EPRI is not currently conducting such testing but is closely following Department of Energy (DOE) sponsored efforts.

EPRI is also conducting research to develop and demonstrate non-destructive evaluation (NDE) techniques that may be deployed in-situ in order to complete the recommended inspections. Inspectors will have limited access to the canister surface within a cask environment that involves high temperature and high radiation. EPRI's research is developing remotely operated vehicles and low profile NDE sensors in order to meet these challenges. EPRI's prototype has been successful in reaching the canister surface through the ventilation ducts and traversing the surface while carrying NDE equipment during functional testing. EPRI also recognizes a need for repair technologies to mitigate any degradation that is found during canister inspections. This is an area where DCSS vendors may ultimately take the lead in order to develop techniques specifically applicable to unique designs. The issues of limited access, high radiation, and high temperature will have to be considered in this area as well.

Considering the challenges associated with canister inspection and repair of any degraded canister conditions, it is important to understand the consequences associated with a CISCC flaw in a used fuel dry storage canister. EPRI has also begun research in this area, starting with a report that evaluates available risk and consequence information (PRAs, dose assessments, failure mode analyses) and defines the scope of additional work needed for consequence analysis that is specific to through-wall CISCC of one or more dry storage canisters. It is possible that the consequences of storing canisters that have lost confinement integrity due to CISCC may be less significant in terms of both dose and cost than the consequences of implementing an inspection and repair program capable of preventing confinement breach.

EPRI's research to address CISCC in used fuel dry storage canisters is part of a much larger effort. The used fuel dry storage cask vendors, the American Society of Mechanical Engineers (ASME), the DOE, the Nuclear Energy Institute (NEI), and the Institute of Nuclear Power Operators (INPO) are also developing industry guidance and tools needed in order to implement and adapt ISFSI aging management programs.

CHLORIDE-INDUCED STRESS CORROSSION CRACKING AGING MANAGEMENT GUIDANCE

This report provides guidance for the development of an aging management plan (AMP) to address the potential for the degradation of external surfaces of austenitic stainless steel canisters due to chloride-induced stress corrosion cracking. Since

CISCC has been identified as the most likely and limiting degradation mechanism that could lead to through-wall penetration of the austenitic stainless steel canister, other atmospheric corrosion mechanisms are conservatively addressed by an AMP developed to address CISCC. At sites with low susceptibility to chloride-induced degradation, performing a limited set of inspections provides sufficient monitoring to address unidentified or unanticipated degradation mechanisms. EPRI's CISCC susceptibility assessment criteria are used in inspection schedule planning, sample selection, and scope expansion upon detection of CISCC. The aging management guidance recommends performing periodic visual inspections of the canister surface for evidence of corrosion, where areas of corrosion are found near welds a follow up inspection is recommended using NDE techniques capable of detecting cracking. Evidence of corrosion found in regions away from welds is used to inform the follow up inspection scope and schedule, but does not require application of NDE. Industry operating experience collected by the Institute of Nuclear Power Operations (INPO) in the ISFSI Aging Management INPO Database (ISFSI AMID) is also taken into consideration for planning inspection scope and frequency. If a canister is found to be in a degraded condition, the licensee Corrective Action Program will be engaged to address the degradation. The report includes an evaluation of the relative cumulative probability of through-wall CISCC for a variety of assumed inspection sample sizes and inspection frequencies. The results show that a sampling approach focused on the most susceptible canisters can optimize the use of inspection resources. The report also includes a summary of potential mitigation techniques that may be applied to prevent or repair CISCC degradation and an example aging management plan.

NON-DESTRUCTIVE EVALUATION TECHNIQUE DEVELOPMENT

EPRI is working with various utilities and vendors to develop methods to support Dry Cask Storage System (DCSS) inspections. EPRI is developing remotely operated vehicles (ROVs) that can access canisters though ventilation ducts while carrying low-profile nondestructive evaluation (NDE) sensors and/or cameras. The equipment must be resistant to the high temperature, high radiation, confined space environments that may be encountered inside a cask. The ROVs should also be able to manipulate the NDE devices (using methods such as visual, ultrasonic, eddy current, guided waves, etc.) in order to obtain relevant data, such as the location of an anomaly or crack indication.

Two ROV models are being developed; one uses magnetic wheels and the other uses vacuum suction in order to maneuver inside the cask. Trials have been conducted to test the functionality of the ROVs along with cameras and inspection devices. A prototype of the magnetic robotic delivery system has been successfully demonstrated in vertical dry storage cask designs. This robotic system has been deployed into two empty cask systems and one cask system loaded with greater than class C waste. Through multiple demonstrations, the system carried cameras, NDE equipment, and collected surface samples. The vacuum suction propelled ROV is continuing to be developed for application in horizontal cask designs. NDE inspection development has shown significant potential to identify defects in canisters.

THROUGH-WALL CISCC CONSEQUENCE ANALYSIS

EPRI is working to provide a summary and evaluation of available references relative to defining the consequences of a canister breach scenario involving chloride-induced stress corrosion cracking (CISCC) of a welded stainless steel canister contained in a dry cask storage system. This effort will conclude in early 2017 and will provide a recommendation for the additional work scope for completing such a consequence analysis on a basis that may be widely applicable to canisters currently in storage. The ultimate goal of such analysis is to provide a proper context for extended dry storage aging management activities. EPRI plans to complete the additional analysis in 2018.

The potential dose to site personnel and the general public associated with radionuclide release via a CISCC through wall flaw in a welded stainless steel canister will be the focus of this effort. Canister storage will be the only phase evaluated in the initial analysis; handling and transportation scenarios are not included. Disaster (missile and flood) scenarios are also beyond the scope of interest; scenarios that postulate a criticality event or loss of structural integrity of the canisters are not considered credible.

References that are potentially relevant to canister breach during extended storage have been identified and are being evaluated as potential inputs or benchmarks for a CISCC consequence analysis. The scenario of interest includes air ingress, reduced heat removal capacity, and potential cladding oxidation as the canister remains in storage and cracking is unmitigated. The evaluation will identify data and results of interest from existing references and describe gaps in knowledge.

The report will provide a description of the specific consequence results that are of key interest relative to dry storage aging management and describe the scope of work that must be completed in order to generate these results.

CONCLUSIONS

EPRI research efforts to address potential CISCC of canisters used in dry cask storage will provide the industry with tools and data that are needed in order ensure continued safe storage for several decades to come. Implementation of aging management guidance using non-destructive evaluation capabilities demonstrated by EPRI will allow industry to determine the extent and significances of CISCC. EPRI's evaluation of the potential consequences of through-wall CISCC will inform follow on actions should it be discovered in any canister(s) currently storing used fuel.

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