2024 White Paper

Steam Generator Management Program: Secondary Side Projects White Paper

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STEAM GENERATOR DEPOSIT MANAGEMENT

Dissolved iron and iron particulates are created via corrosion in the balance-of-plant and become part of the secondary side flow. Due to thermodynamics and boiling of water in the steam generator (SG), most iron that enters the SG via feedwater will remain in the SG. Some, but not much, iron is removed via SG blowdown. Since iron is constantly being deposited inside the SG, managing these deposits is an important consideration for SG lifetime analysis (Reference: J. Riznic, Steam Generators for Nuclear Power Plants. 2017). Deposit management is an active area of research in EPRI's Steam Generator Management Program (SGMP).

There are three primary locations for SG deposits are listed below.

1. Top of tubesheet (TTS) where deposits form sludge piles and hard tube collars. Deposits in this location are generally controlled by sludge lancing. Hard deposits can result in tube denting and corrosion degradation for material susceptible to corrosion.

   Sludge is generally particulate iron that falls to the TTS region. Often the largest regions of accumulations are where flow in the SG slows down allowing particles to drop out of normal recirculation flow. Collars are formed by consolidation of sludge on the tube at the tubesheet region aided by the heat from the drying out of deposits. Deposits can harbor contaminates and insulate the TTS region increasing temperature which increases tube cracking risks. Collars often contain other binding species such as aluminum or copper which can make them harder and tough to remove.

   Corrosion product formation can expand into the tubes resulting in tube deformation (denting). This deformation increases stresses on the tubes which increases cracking risks. The denting affects the NDE program by increasing required special examinations or possibly by blocking tubes enough that probes cannot be passed through tubes.

   A common question is how frequently sludge lancing should be performed to be effective. EPRI SGMP has examined the differences between plants that sludge lance every outage and plants that operate longer between sludge lancing. Data gathered shows that more sludge is removed over time if sludge lancing is performed every outage. Hard collars form withing one cycle meaning sludge lancing more frequently will not fully prevent collar formation.

2. Tube Freespan surfaces where deposits form scale on the tube outside surfaces. These deposits affect thermal performance of the SG by limiting steam production and plant output.

   Tube scale forms when iron particles or dissolved iron are deposited onto the outer surface of SG tubes to form a thick layer. Deposits can form at any point along a tube on both the hot and cold legs. However, tube scale is generally thickest on the hot leg of the SG in the upper portions of the bundle. When thick enough, coefficient of thermal expansion differences between the scale and the tube can create enough stress to cause scale to become detached from the tube surface in localized areas, typically referred to as exfoliation.

Tube scale is a complex formation on the tube surfaces which is usually somewhat porous, and this porous nature creates enhanced heat transfer compared to a bare tube. Scale properties change over time resulting in changes in heat transfer performance. Deposits can thicken which increases thermal resistance, and often have microscopic pores and chimneys that can increase the effectiveness of heat transfer. Deposit morphology will change with increasing deposition. When scale exfoliates, this also changes the heat transfer effectiveness.

During a down-power event the chemistry conditions change allowing impurities to be released from crevices into the secondary flow. This is called Hideout Return. A hideout return study measures the chemistry at specific intervals while down-powering and relates them to the amount and type of impurities present in the SG. Trending results over multiple cycles is key to understanding long term health of the SGs. It is not unusual for new SGs operated with good water chemistry to have little measurable hideout return. Prompt hideout return measurements are often associated with impurities on tube scale. Delayed hideout return measurements are more associated with impurities trapped in crevices.

3. Tube support plate broached holes where deposits form on the leading edge of the broached holes and reduce the flow area. Heavy blockage can result in flow redistribution in the SG leading to water level oscillation or other operational concerns.

   Chemical cleaning is an effective way to reduce deposit loading in the SG. The timing of a chemical cleaning is determined by each plant. Some considerations for timing are: steam generator performance declining due to loss of heat transfer, deposit buildup at tube supports, deposit loading, deposit compositions identified which could result in tube degradation, or onset of top of tubesheet denting.

MANAGING FOREIGN MATERIAL IN THE SG BUNDLE

EPRI SGMP has conducted research on foreign objects and foreign object wear and has provided tools to members for inspection, removal strategies, and assessments. One project completed in 2010 provided a prioritization strategy for foreign object removal decisions based primarily on operating experience. This has been successfully used by most U.S. plants. These reports help the members to understand the risks of leaving foreign objects in the bundle. When assessing the need to plug tubes due to foreign object wear, the same 40% through wall plugging criteria as used for other wear mechanisms is used.

According to the research performed to supply prioritization strategies, the most severe tube wear from foreign objects will occur in the high cross flow regions around the periphery of the tube bundle at the top of the tubesheet. According to data compiled by SGMP in 2012, no wear events have caused primary to secondary leakage from tubes with foreign object wear at a tube support location. Some plants have their OEM vendor provide the thermal hydraulic conditions specific to their SGs and develop site-specific strategies for managing foreign objects.

SGMP's SG thermal hydraulic code, ATHOS, is no longer supported by EPRI SGMP due to the limitations of the CFD code. Some organizations have the ATHOS code and have further developed it with pre and post processors. SGMP is currently working on a new SG thermal hydraulic code that will use commercial software. ATHOS and the new code use a porous media approach.

Another SGMP project that completed the first phase in 2023 provides a software for evaluating foreign objects in the SG tube bundle. This software calculates the SG tube wear from a given object at a specific bundle location. This project's deliverables are not publicly available. In this research, the foreign objects are located near the top of the tubesheet where the tube in not vibrating only the foreign object displays movement. Turbulence force spectrum in the tube bundle near the foreign object is calculated and the spectrum is used to estimate the sliding distance of the foreign object on the tube outside diameter. Steady and turbulent drag forces are parameters for estimating contact force between the foreign object and the tube. Turbulent lift force is a parameter creating the foreign object sliding motion on the tube surface. The fluid force data developed in this research is only applicable for the top of the tubesheet region and is based on results from a test rig designed to simulate the top of the tubesheet region. Thus, the fluid force data should not be used for any other regions in the steam generator.

The definition of the parameter, Sc, is given as the surface area of a cylinder with the same diameter as the equivalent diameter, d, of the foreign object. The height of the cylinder is the same as the height of the foreign object. All foreign objects tested had a length equal to the tube pitch. In the analyzed conditions, there is not a significant difference between the tube pitch and the length of the foreign object.

There will be a difference when considering other places in the tube bundle. SGMP began the next phase to investigate foreign objects located at tube support plates.

Some steam generator designs include a foreign material trapping device, called spray cans. When upper internals inspections are performed, these spray cans are inspected, and any foreign material found can be removed.

In the U.S., utilities typically use vendors to provide foreign object search and retrieval. The tooling is proprietary to the vendors.

STEAM GENERATOR INSPECTION, ASSESSMENT, AND MANAGEMENT STRATEGIES

Eddy current is the method used in the U.S. to inspection steam generator tubes and the assessments follow prescribed instructions in SGMP guidelines.

Eddy current bobbin probes can detect tube support structures. This is primarily used for determining location. There is no requirement to inspect anti-vibration bars. With improved material in support structures, there is no concern for degradation of these structures. Wear in tubes at anti-vibration bars and other support structures is caused by vibration and high cross flow. The level of wear identified in steam generator tubes is dependent on the steam generator design and manufacturing process. Some SG models have experienced little to no wear while others have thousands of wear indications.

SGMP is currently conducting research to determine the effect of deposits on eddy current signals. This project began in 2023.

In the U.S., plants have optimized their steam generator inspections by using Technical Specification Task Force (TSTF) – 577. Details on operating intervals and required scope can be found on the U.S. NRC website, including preservice inspections.

Plants that experience primary to secondary leakage during operation are required to take actions, including shutting down the unit at levels prescribed by SGMP guidelines. Even at small levels of leakage (113 liters per day), a secondary side hydro test is most often able to help identify the leaking tube. Helium leak testing is not used in the U.S. to identify leaking tubes.

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