

## Sludge Deposit Mapping for Steam Generators

Ivan Rep, Tomislav Tomašić, Darko Barilar

INETEC – Institute for Nuclear Technology

Dolenica 28, Lučko, Croatia

[ivan.rep@inetec.hr](mailto:ivan.rep@inetec.hr), [tomislav.tomasic@inetec.hr](mailto:tomislav.tomasic@inetec.hr), [darko.barilar@inetec.hr](mailto:darko.barilar@inetec.hr)

### ABSTRACT

During plant operation, corrosion products from feedwater, drain and condensate system accumulate on the secondary side of steam generator in form of scaled deposits around the tubes and sludge piles on top of the tubesheet. These deposits increase potential for corrosion, affect fluid flow and reduce heat transfer efficiency of the steam generator.

Using data obtained during periodical eddy current examination of steam generator tubing, information on sludge deposit location and thickness is extracted from low frequency absolute channels. Sludge deposits can be detected over the whole length of the inspected tube. Using automatic analysis deposit results are provided within 36 hours after the inspection. Results are imported in Sludge Mapping software and presented in 3D visualization of steam generator. Both PWR and VVER steam generator visualization is supported.

Sludge mapping software provides visual information on sludge deposit thickness using color code and by calculation position of sludge indication, software draws the indication on the location within the steam generator where indication was found. Sludge mapping software provides information on heavy sludge loading areas of steam generator and can help with tracking of sludge build-up over time that can be used for optimizing steam generator maintenance.

This paper presents INETEC's Sludge Mapping solution, its functionality and features for visualization of sludge deposit location and thickness within the steam generator.

**Keywords:** *steam generator, NDE, sludge deposit, sludge mapping*

### 1 INTRODUCTION

Steam generators are primary circuit components that are used for transfer of thermal energy from primary circuit water to secondary circuit water and steam. Thermal energy transferred to secondary side is further transformed into electrical energy in the steam turbine. Due to its vital role and the fact that complex water flows occur within steam generator primary and secondary side, it is critical that the maximum efficiency of heat transfer is realized.

As the level of control for the secondary side water is somewhat lower compared to the primary side water, secondary side water includes various deposits, like corrosion products from feedwater, drain and condensate system that can accumulate on the outside surface of the tubes. Such deposits on the secondary side of the tube can reduce the heat transfer capability which has two major effects: firstly, lowered heat transfer capability lessens the efficiency of the entire heat transfer process and therefore reduces efficiency of the entire plant operation and secondly, reduced capability of tube to remove heat generated on primary side creates an environment susceptible to development of degradation on the secondary side of the heat exchanger tubes. Tubes with large accumulation of sludge on the secondary side are ideal location for development of degradation and various operational experience has verified initiation of such degradation. [1]

Nuclear industry has developed number of different methods that can be utilized for removal of sludge deposits from the secondary side. Earlier solutions were based on chemical methods but such approach can affect chemical balance of the secondary side water and despite short term benefits can create long-term consequences and instability. As an answer to sludge removal challenge, mechanical methods of sludge removal were developed that are based on application of water spray under pressure that breaks down sludge deposits in smaller, free particles.

However, one of the main issues when applying any sludge deposit removal process is to determine whether the total amount of the sludge in the steam generator is so large that removal actions are necessary or not. And once it is determined that sludge removal is necessary, it is important to identify what are the areas most affected by the sludge depositions and where majority of the removal efforts should be directed.

In recent years sludge deposit mapping tools have proven to be a very valuable tool for nuclear power plant system engineers in determining the total amount of sludge deposits in the steam generator and the distribution of the deposits in the steam generator. Sludge deposit mapping is based on use of data obtained through standard eddy current inspection of steam generator heat exchanger tubes. From this data, through sludge mapping process, information is obtained about the amount and distribution of sludge deposits.

## **2 SLUDGE MEASUREMENT CONCEPT AND MODEL**

Sludge deposit mapping uses data collected during the standard periodic eddy current inspections of steam generator tubes that are scheduled to be performed during regular outages of the power plant. One of the strongest and most important advantages for sludge mapping process is that mapping is performed on the same data that is collected during regular eddy current inspection. No additional activities or additional data collection is necessary and no additional inspection time is required and such concept results in same outage time, whether the sludge mapping is performed or not.

In modern applications, eddy current inspections are performed by multi-frequency technique and usually responses on higher frequencies are used for defect detection, confirmation and sizing while and responses on lowest frequency are used for determination of locations of support structures on the steam generator tube and lowest frequency is often referred as “locator frequency”. Response on absolute channel on “locator frequency” is the only information of interest that is used for sludge location determination and sludge length and thickness measurements as shown in Figure 1.

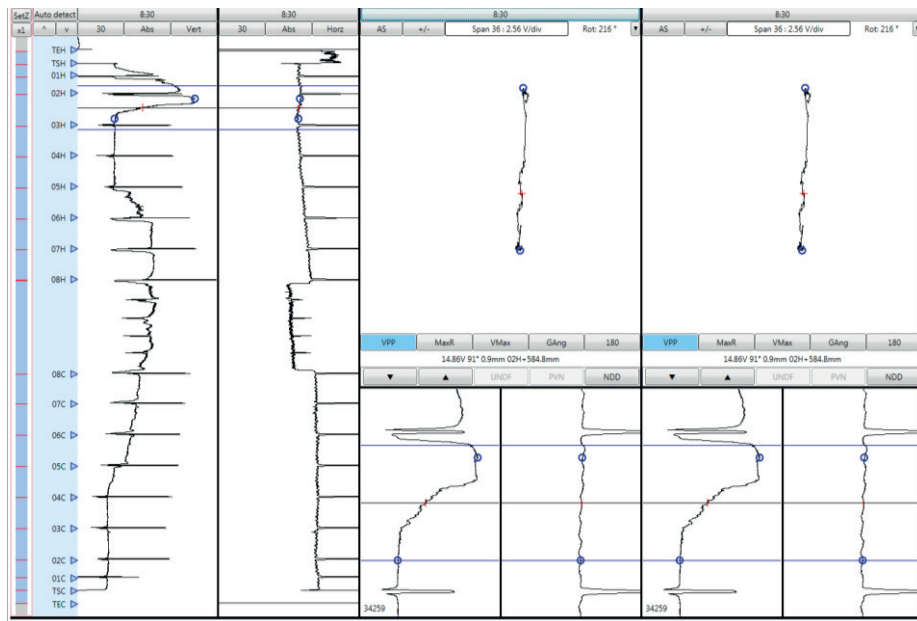


Figure 1 Example of sludge signals on “locator frequency”

Eddy current data of the “locator frequency” absolute channel are examined for the existence of sludge signals and in case that such signals are observed, location and sludge length and thickness are reported. Earliest sludge mapping activities were performed as manual analysis of certain regions of the steam generator where largest accumulations of the deposits were existent, usually areas above top-of-tube sheet of the hot leg of the steam generator.

With the advent of computer technology and development of automatized eddy current analysis that applies computer algorithms for evaluation of the eddy current data more complex arrangements for sludge detection and measurement became available. Such solutions are based on selection of the appropriate measurement model that offer representable measurement of sludge dimensions and once the measurement model is selected it can be applied through measurement algorithm for the entire length of the tube, for larger number of the tubes.

## 2.1 Sludge measurement model

For achieving adequate measurement capability of the sludge mapping system careful selection of the parameters for the measurement must be done. Measurement of the sludge deposits provides information about the following deposit dimensions:

- Deposit location along the axis of the tube
- Deposit length (or height on vertical steam generators)
- Deposit thickness

Deposit location along the axis of the tube is determined by same method that is applied in standard eddy current inspections, where location is calculated from the speed of the probe and the sample rate of the eddy current instrumentation. Deposit length is determined in similar fashion. By using the locations where amplitude of sludge deposit signal exceeds certain threshold values, start and end location for sludge deposit are calculated. However, accumulations are usually related to the support structures in the steam generators and are deposits are adjacent to the structures.

Deposit thickness is the parameter of sludge deposit that is most challenging and requires most experiments and testing to achieve adequate measurement capability. For deposit thickness measurement amplitude dependant curve is used that correlates amplitude of the sludge deposit

signal with thickness of the sludge deposit. Such measurement curves are common in eddy current software and higher amplitude of the measured signal will result with higher thickness of the deposit. Real challenge is to develop a curve that will provide realistic measurement of deposit thickness and such task is usually done in an experimental way.

Experiments are performed on tests specimens with different thickness of sludge layers around the tube. Common approach is that imitation of sludge is created based on the results of the sludge chemical analysis from the actual steam generators. Data with chemical composition of the sludge is available, as analysis is frequently performed in nuclear power plants. Based on such chemical composition, mixtures with similar characteristics are created and used as simulation of sludge. In recent times, efforts have been made to acquire clean sludge from the secondary side of steam generators and such sludge can also be used for preparation of sludge mapping calibration standards.

Figure 2 shows examples of dry sludge retrieved from actual steam generator secondary side. Such clean sludge is packed in rings of various thickness and compactness and put around defect free steam generator tube.

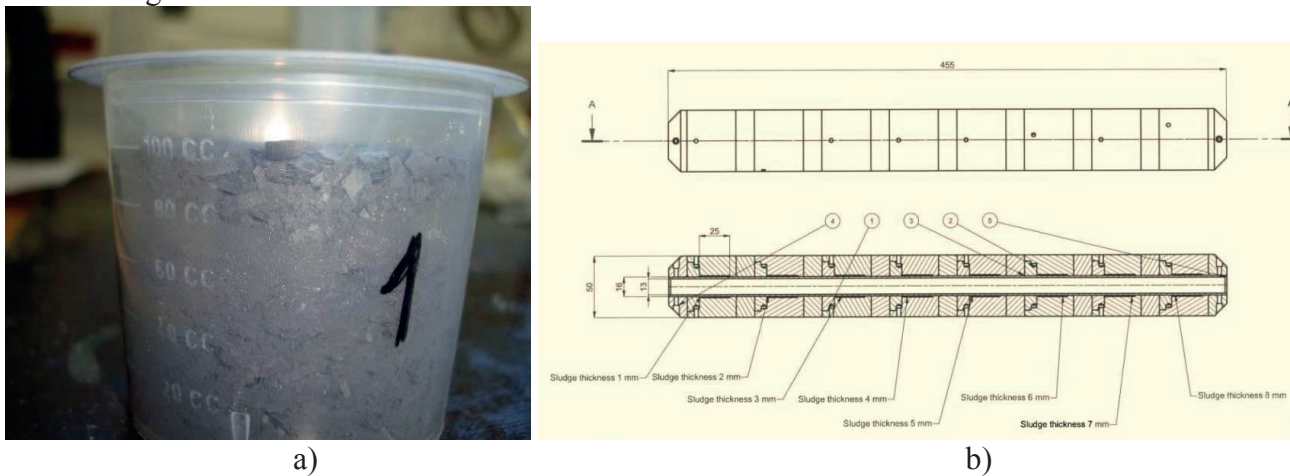


Figure 2 Sludge calibration standard: a) dry sludge retrieved from secondary side, b) example of calibration standard for sludge thickness measurement

Once all the parameters of the measurement model are selected, the analysis of sludge can be performed. As number of tubes and support structures in steam generator is very large, manual analysis approach to sludge mapping has proven to be a laborious effort. Initially, only areas above top-of-tubesheet on the hot legs of the steam generators, often referred in the industry as "sludge pile" were examined for sludge and only the height of sludge accumulations from the tubesheet was measured. Automatic analysis enabled more options and capabilities for sludge mapping, and such algorithms can be applied on the entire length of the tube with possibility of different measurement grids and settings.

## 2.2 Automatic measurement algorithm

Automatic analysis of eddy current data refers to application of computer algorithms that are applied on eddy current data with purpose of evaluating the data. Usually application is such that algorithms are developed and set in such way that degradation existing on the tube and recorded in the eddy current data will be detected and reported. As sludge signals are clearly distinguishable on the eddy current data, automatic analysis algorithms can also be set so that all signals meeting sludge reporting criteria are detected and reported.

When automatic algorithm is applied on the eddy current data, such evaluation results with significant amount of data and reported sludge occurrences. Most common approaches are to divide

steam generator tube into sections and in each one of them perform measurement or to perform measurements and evaluation only on segments of the tube adjacent to each support structure. Table 1 presents average numbers of reported sludge occurrences in steam generator for different settings of the automatic sludge mapping algorithm.

Table 1 Average number of reported sludge occurrences for different measurement algorithm

Type of sludge measurement algorithm	Number of results per SG
Axial grid with 64 divisions per tube	~ 350 000
Axial grid with 128 divisions per tube	~ 700 000
Axial grid with 256 divisions per tube	~ 1 400 000
Axial grid with measurement only adjacent to support structures	~ 40 000

As it can be seen in table above, automatic algorithms with strict division of the tube in sections results in significantly larger number of measurements and larger amount of data to process. For each section measurement will be performed and values will be created. Algorithm setting where evaluation and measurement is performed only on sections adjacent to support structures usually results with a lower amount of data and such application is especially convenient in applications for horizontal steam generators.

Normally during steam generator eddy current inspections acquired data is organized in calibration groups, where the data from certain number of tubes is recorded and each tube is recorded and archived as separate file. For each calibration group usually single textual report file is created that consists of all report entries for all tubes inside that specific calibration group. Each report entry (sludge measurement result) is one line in group report textual file.

Once the process of sludge measurement is completed for the entire steam generator, from obtained results database with results can be created and various processing of results can be performed as well as preparation of sludge distributions in different modes.

### 3 3D VISUAL MAPPING OF DEPOSITS

After the data has been processed it is imported into the sludge mapping visualization software. This software provides visual information on sludge deposit thickness using the color code which by default shows thicker deposits in red and thinner deposits in blue. The actual color scale can be selected from a set of predefined color scales.

The user interface displays a 3D model of the steam generator, showing all the tubes, supports and the sludge data. It provides a set of standard controls for 3D space navigation (rotate, zoom, pan) and specific controls for slicing and data display. The position of each sludge point is calculated from the imported data and drawn on the location in steam generator where the indication was found.



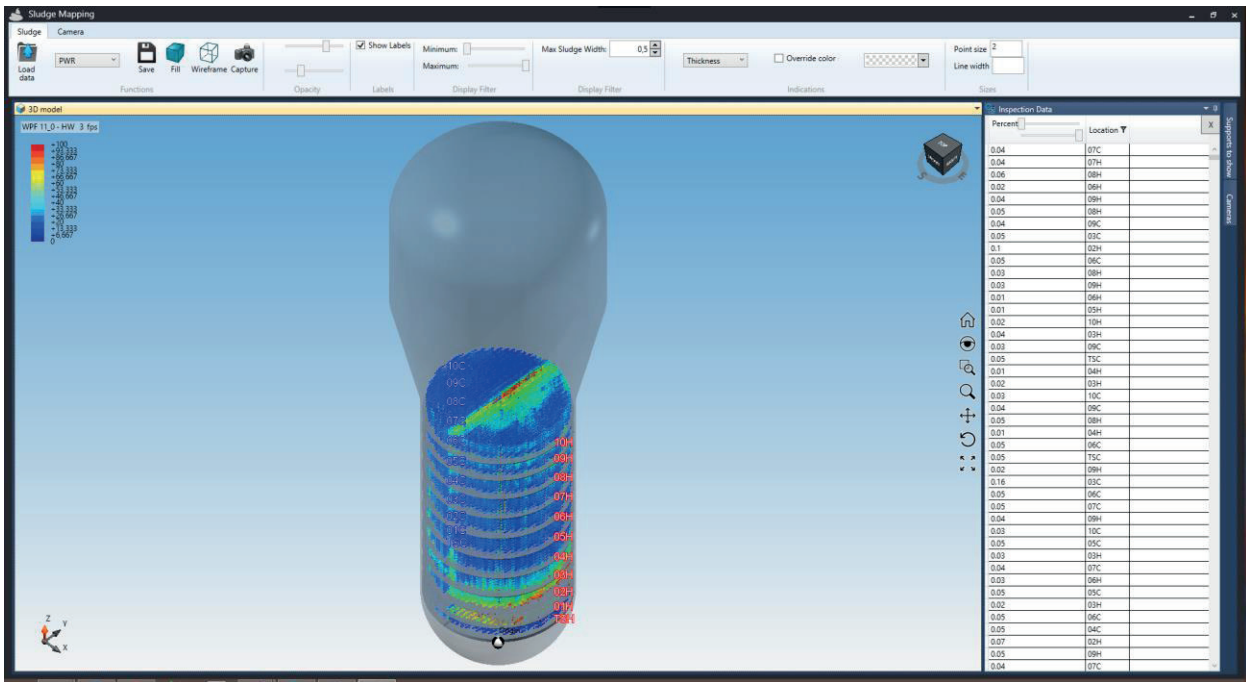


Figure 3 Sludge mapping user interface

The software supports two major SG types, the PWR and VVER and their subtypes. Steam generator configuration data is saved in a configuration file which enables the user to simply add a new custom steam generator type. The configuration file contains all the information about the generator geometry, tube positions and the positions and names of each support.

The sludge points shown in the visualization can be filtered on the fly by using the filters available in the header of each column of the data table. User can filter the data by position (row, column or section), sludge thickness, the support on which the measurement was made and the distance from it.

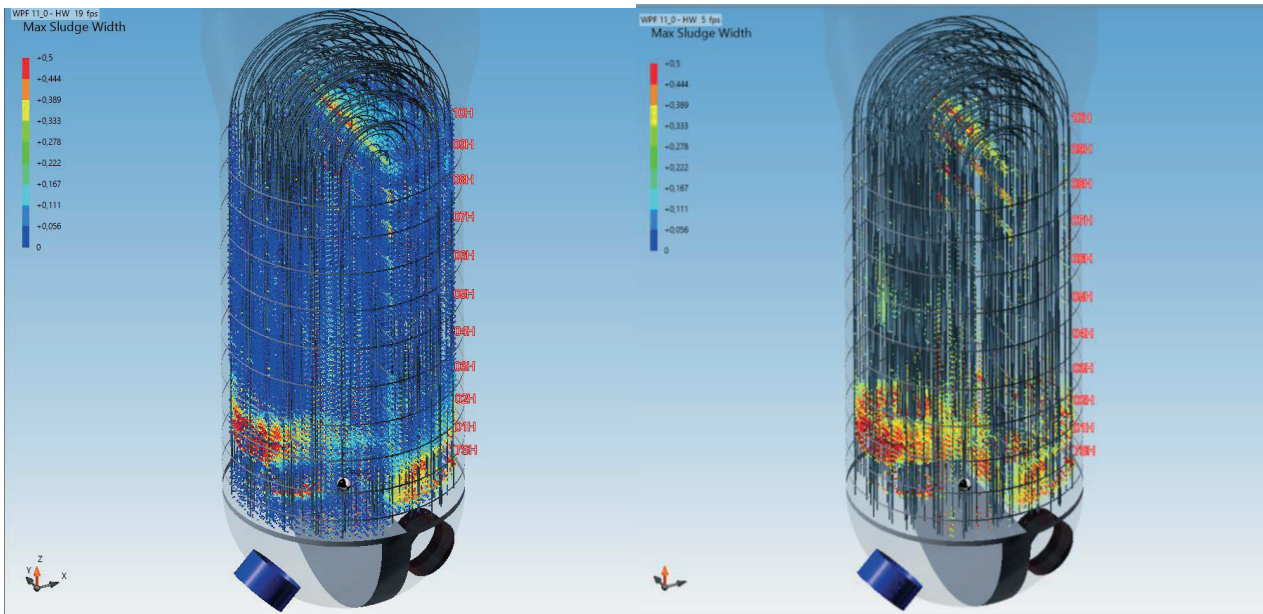


Figure 4 Example of filtering the data by sludge thickness

The SG model can be sliced by one or multiple arbitrary planes to show the sections of interest. By using two slicing planes, a cutout between the two supports can easily be made. These

features allow for an easy estimation of the heavy sludge deposit areas in the steam generator and can also help with tracking of sludge build-up over time that can be used for optimizing steam generator maintenance.

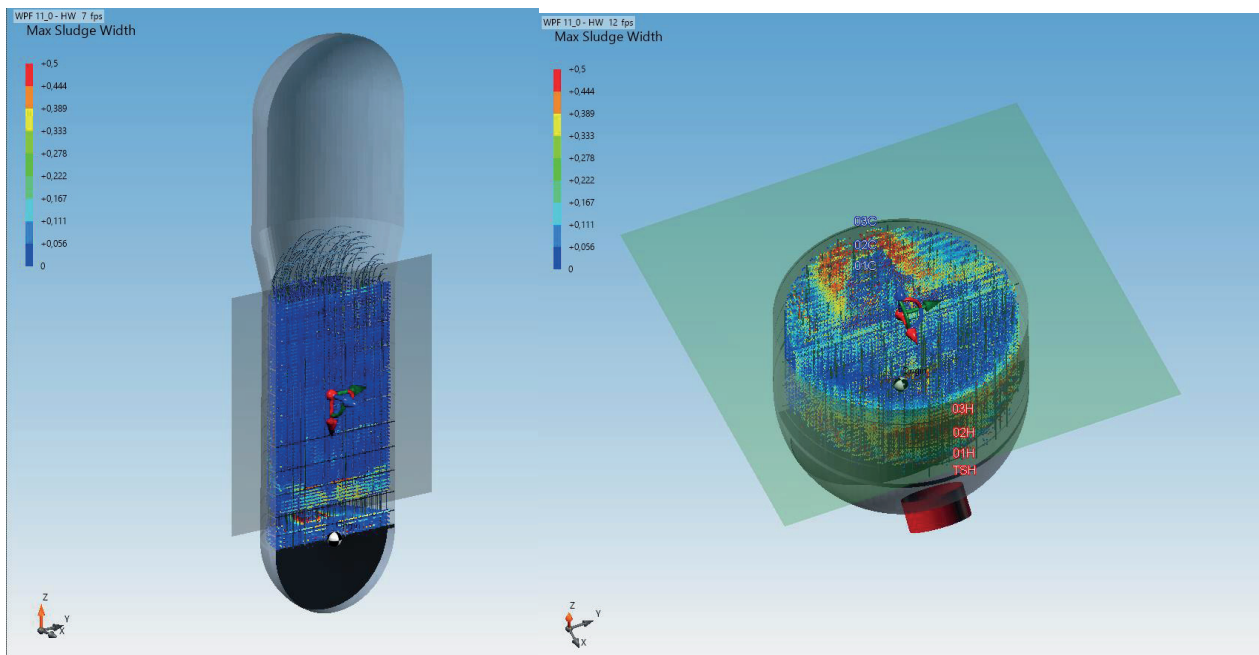


Figure 5 Examples of slicing the generator model by different planes

Automatic generation of a sludge deposit mapping report is supported. The generated report contains all the statistics about the sludge position relative to the supports and the estimates of the sludge mass. User can also predefine multiple 3D viewpoint positions which can later be automatically integrated into the report. This greatly speeds up and simplifies the process of generating of quality reports.

#### 4 CONCLUSION

Sludge deposit mapping of steam generator tubes is an activity that can significantly enhance operational capability of nuclear power plants. Accumulations of sludge on the secondary side of steam generator tubes can have significant impact on the functionality of steam generators as sludge deposits reduce the heat transfer capability and overall efficiency of the power plant, and additionally sludge accumulations create environment susceptible to development of tube degradation. Recent operational experience has also emphasized mechanisms like tube support clogging [4] that can also have impact on steam generator tubes. System engineers in nuclear power plants require more information about the amount and distribution of sludge on secondary side of steam generators and sludge deposit mapping is solution for obtaining such information.

Modern computer technology has enabled use of automatic eddy current data analysis and such solution offers quick method of evaluating large volumes of eddy current data for existence of sludge. Sludge measurement algorithms can perform evaluation of eddy current data in parallel with standard eddy current inspection of steam generators and such capabilities result in possibility that sludge mapping of steam generator can be finalized in very short time after the removal of equipment for standard eddy current inspection. Such features allow system engineers to have information about sludge deposits and make decisions even during outage period in which eddy current inspection was performed. Large amount of available data and three-dimensional

presentations of distributions of sludge deposits throughout secondary side of steam generators offer possibility of better understanding sludge creation and other related phenomena. Sludge deposit mapping is an activity that augments operation of nuclear power plant and ensures necessary background for activities that can further improve the efficiency and safety of nuclear power plants.

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