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Sludge Removal at Krško NPP Steam Generators during Outage

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ABSTRACT

Sludge removal is performed on two steam generators (SG's) at the Krško Nuclear Power Plant (NEK) during every outage. SG's are a meeting point of four major plant systems: Reactor Coolant System (RC) on the primary side and three systems on the secondary side – Auxiliary Feedwater System (AF), Main Feedwater System (FW) and Main Steam System (MS).

Sludge removal activities take place on the secondary side of the SG's on the top of the tube sheet. It consists of classical Sludge Lancing (SL) which is done by spraying water at different angles (30°, 90°, 150°) between the tube gaps in the steam generator tube bundle with a pressure around 220 bars. Another method is Inner Bundle Lancing (IBL) which means spraying water at a much higher pressure (NEK's contractor reached a pressure of approximately 590 bars). Such water is sprayed directly on the top of the tube sheet with a robot guided lance which is placed inside a steam generator. The robot is controlled by an operator and at times fully autonomous to provide the highest protection measures possible. After these activities, a televisual inspection (TVI) of the top of the tube sheet is performed to access the hard sludge area and to search for potential foreign objects in the SG's. If an object is found, an attempt to retrieve it would usually take place. Other methods of sludge removal as upper bundle flushing or chemical cleaning have not been implemented in NEK thus far.

Since the power plant uprate in May 2000, NEK conducted SL on both SG's every outage with IBL in 2013 and 2015 and the same method was used in the 2018 outage. The purpose of these activities is mainly to extend the full load operation of the plant, prevent denting processes in the SG's from occurring, stop the buildup of hard sludge area to increase/sustain efficiency and remove foreign objects found in the SG's.

SG's U-tubes are a barrier between the primary side coolant and the secondary side of NEK and the environment. Therefore, it is crucial to keep the highest level of integrity of the U-tubes because any leak could potentially mean a release of radioactive material to the atmosphere.

This paper describes the purpose and workflow of sludge removal in NEK.

Keywords: *steam generators (SG's), Sludge Lancing (SL), Inner Bundle Lancing (IBL), televisual inspection (TVI), Foreign Object Search and Retrieval (FOSAR), Krško Nuclear Power Plant (NEK)*

1 INTRODUCTION

Sludge removal activities are performed on two steam generators (SG's) during every outage. SG's are a meeting point of four major systems which are Reactor Coolant System (RC) on the primary side and the three systems on the secondary side: Auxiliary Feedwater System (AF), Main Feedwater System (FW) and Main Steam System (MS).

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Steam generators are safety related components that are required to operate during normal, abnormal and emergency conditions. During normal power operation steam from steam generators is supplied to the turbine. During shutdown conditions, they are a vital component in decay heat removal process. Additionally, steam generators act as a third barrier for preventing radioactive releases into the environment. Due to this the cleanliness and operability of steam generators is vital for safe operation.

Sludge removal activities take place on the secondary side of the SG's on the top of the tube sheet. It consists of classical Sludge Lancing (SL) which is done by spraying water at different angles (30°, 90°, 150°) between the tube gaps in the steam generator tube bundle with a pressure around 220 bars. Another method is Inner Bundle Lancing (IBL) which means spraying water at a much higher pressure (NEK's contractor reached a pressure of approximately 590 bars). Such water is sprayed directly on the top of the tube sheet with a robot guided lance which is placed inside a steam generator. The robot is controlled by an operator and at times fully autonomous to provide the highest protection measures possible. After these activities, a televisual inspection (TVI) of the top of the tube sheet is performed to access the hard sludge area and to search for potential foreign objects in the SG's. If an object is found, an attempt to retrieve it would usually take place.

This paper describes the sludge removal process in NEK from start to finish. Descriptions from setting up the equipment, differences between Sludge Lancing and Inner Bundle Lancing, and the purpose of TV inspection and FOSAR attempts will be included. The paper will offer an insight into the results of this year's outage as well.

2 SETUP OF EQUIPMENT

Arrival of equipment and its radiological check take place about 7-10 days prior the start of operations. After the arrival of personnel, a detailed pre-job briefing and basic general employee trainings are conducted. 1-2 days prior to start of operations, a rough setup of the equipment is done, which includes setting up the hoses, cables, control units etc. inside the reactor building (RB). For the SL/IBL activities, containment integrity is not required, so as soon that's the case, the equipment inside the RB and outside of it is connected and water is recirculated through the Sludge Lancing system. The first analysis must prove the cleanliness of the SL/IBL equipment prior to introduction of that water inside the NEK's SG's.

The equipment for SL/IBL consists of a Sludge Lancing robot, diaphragm drain pumps, buffer tank, filter units (mechanical), storage tank with bypass cooling and resin filter system, high pressure pumps, control unit and hoses and valves.

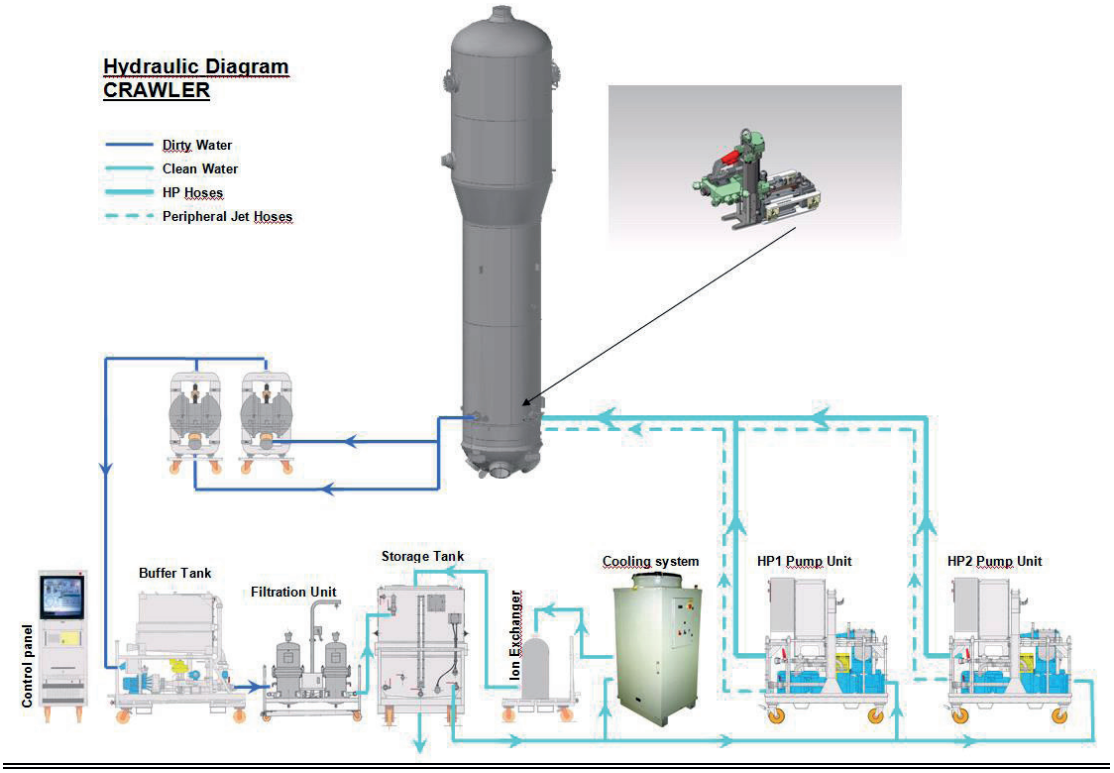

Figure 1[1]: Equipment setup for SL/IBL

3 OPERATION

3.1 Sludge Lancing (SL)

A SL robot is positioned and operated in the NO-Tube lane in order to remove the loosen sludge accumulated inside the hot leg (HL) and cold leg (CL) out of the tube bundle. The water is directed to the SG through high pressure (HP) pumps (200b and 250b). Then the mixture of water plus sludge is removed from the SG by diaphragm pumps and trapped by high performance filtering elements. The water is then conducted to a storage tank, to be re-injected into the steam generator by high pressure and peripheral jets pumps (see Figure 1). A bypass loop cools the water from the storage tank and purifies it so the SL cleaning process uses as neutral water as possible inside the SG's.

Because of the triangular pitch of the Krško SG's, the SL robot can be used in 90° direction and 30°/150° from the NO-Tube lane (see Figure 2). With the orientation of jet stream in the direction of 30°, 90° and 150°, it is possible to reach both higher number of passes of the HP jets and various areas of the tube bundle compared to cleaning only at 90°. In this manner, the "shadow areas" which are behind the U-tubes from perpendicular direction of the NO-Tube lane are also reached and cleaned.

[1] All pictures in the document are property of SUEZ RV OSIS SUD-EST.

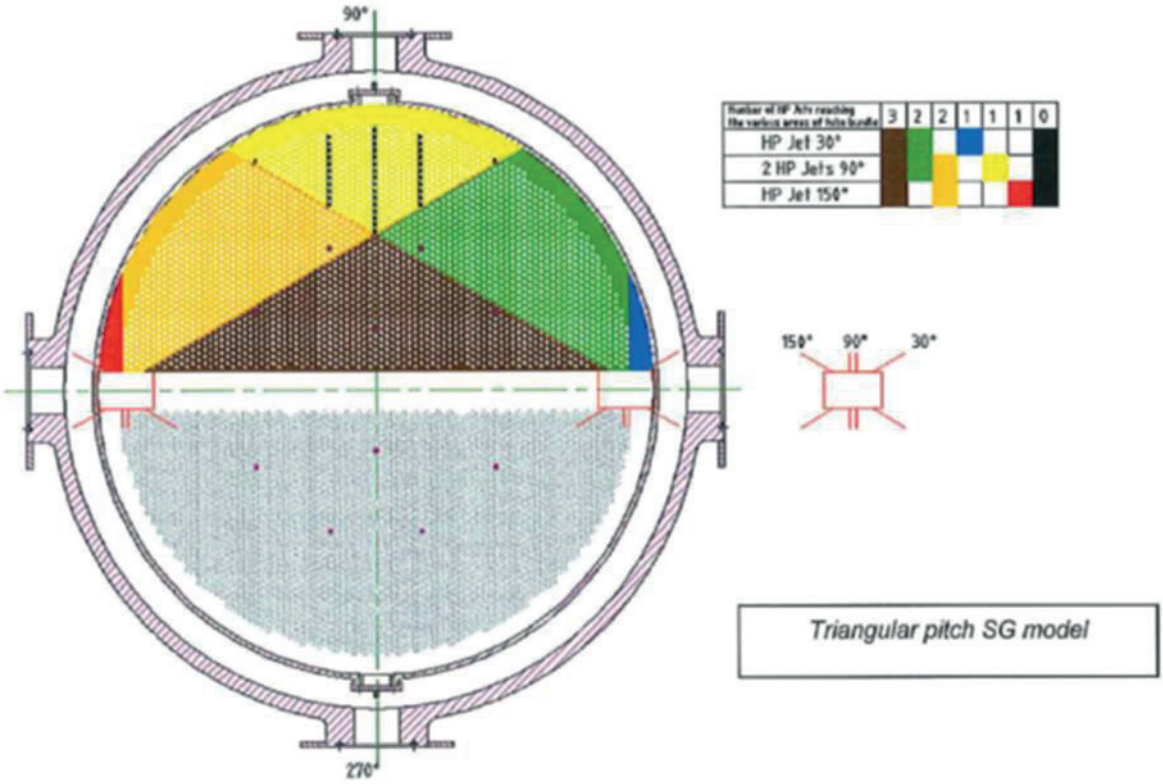

Figure 2: Direction of HP jets inside the SG during SL cleaning phase

3.2 Inner Bundle Lancing (IBL)

A crawler (see Figure 3) installed in the NO-Tube lane is equipped with a HP lance which can enter between tubes. Using a 590b pressure, it realizes the Inner Bundle Lancing (IBL). Its goal is to break hard sludge deposits inside the tube bundle in the very low velocity water area. Using two different heads, the lance can be guided at 90° and at 150°. By using different hand hole (HH), the HP jet can cover three directions of the triangular pitch. IBL lance travels between the tube bundle in two different heights: at 6 and 20 cm above the tube sheet. The head is self-balancing with a jet stream oriented directly down and up for counter balance.

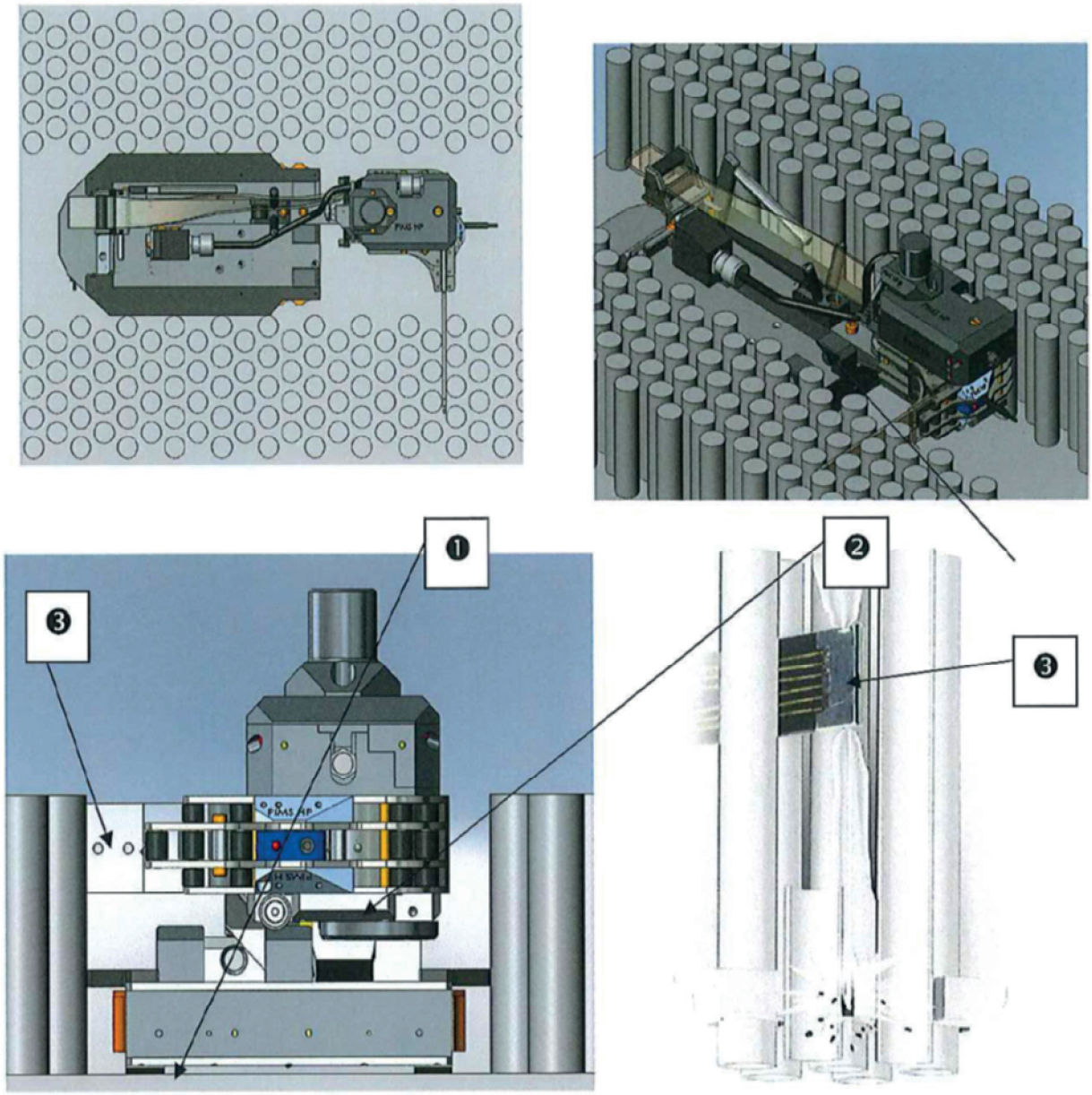

Figure 3: IBL crawler and HP jet position

1. Crawler moving straight in the NO-Tube lane
2. Push-pull system to guide the lance inside the tube bundle
3. Hard Sludge Lance with working jet, to the bottom, and counterbalanced jet, to the top

3.3 Drying

After SL, the SG must be prepared for TV inspection. Due to high humidity inside the SG after SL/IBL phase, the camera lens gets foggy and blurry, therefore the drying equipment is introduced. The drying equipment consists of two intake units with HEPA filters, double fan unit with heater and connection hoses. The discharge hoses are connected to the SG's inspection holes in the direction of the NO-Tube lane with the perpendicular inspection closed at the time. At least one secondary manway must be opened to effectively dry the SG prior to TV inspection. This process lasts about 10 hours.

3.4 TV inspection and FOSAR

Remote visual inspection is performed to inspect the inner tubes on the tube sheet, after the Sludge Lancing, to check the cleanliness, locate eventual foreign objects and check the result of the Sludge Lancing. A crawler starts moving in the NO-Tube lane (see Figure 4). It is equipped with a push-pull mechanism and a lance (or strip). The lance goes into each inter column at 90°, from the NO-Tube lane to the peripheral lane. The space between each U-tube is approximately 3.6 mm when the tubes are new and no sludge has been accumulated. Small layer of sludge on the tube can block a camera path regardless of the fact, that the lens is only 2.7 mm thick (see Figure 5). Another obstacle inside the SG is the space between a Tie-Rod and a U-tube.

Figure 4: Crawler moving in the NO-Tube lane

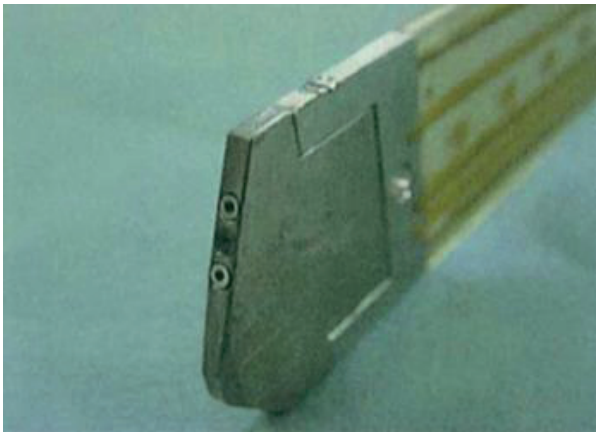

Figure 5: 2.7 mm camera strip with lens

If a foreign object is found inside the SG, its location is carefully noted, the object is categorized, the length is approximated, as is the weight and the material. The categorization is carried out using the EPRI Technical Report 1020989 Steam Generator Management Program: Foreign Object Prioritization Strategy for Triangular Pitch Steam Generators. Based on the shape, size and position of the object, its general location inside the SG and some other factors, a decision will be made if a retrieval attempt is performed. TV crawler in that case acts as a guide for the operator who manually inserts the tool and tries to grab the object stuck inside the SG. Success rate of these attempts varies and depends mostly on the skill of the operator of the FOSAR tool, experience and some luck. If an object is retrieved, a detailed analysis is conducted to determine its origin and structure. If the attempt fails, the location is reported and ECT inspection of the contact and surrounding tubes is performed at the shortest possible interval. Some objects are monitored during the entire time of operations in the SG's.

4 RESULTS

4.1 SG1 results after Sludge Lancing

In 2018 outage, NEK implemented SL only at SG1. No IBL on SG1 was performed. In the cold leg, the hard sludge area is difficult to characterize. The zone is extended (compared to the last TV inspection) but it is not important in height. No fixed foreign objects are present (see Figure 6).

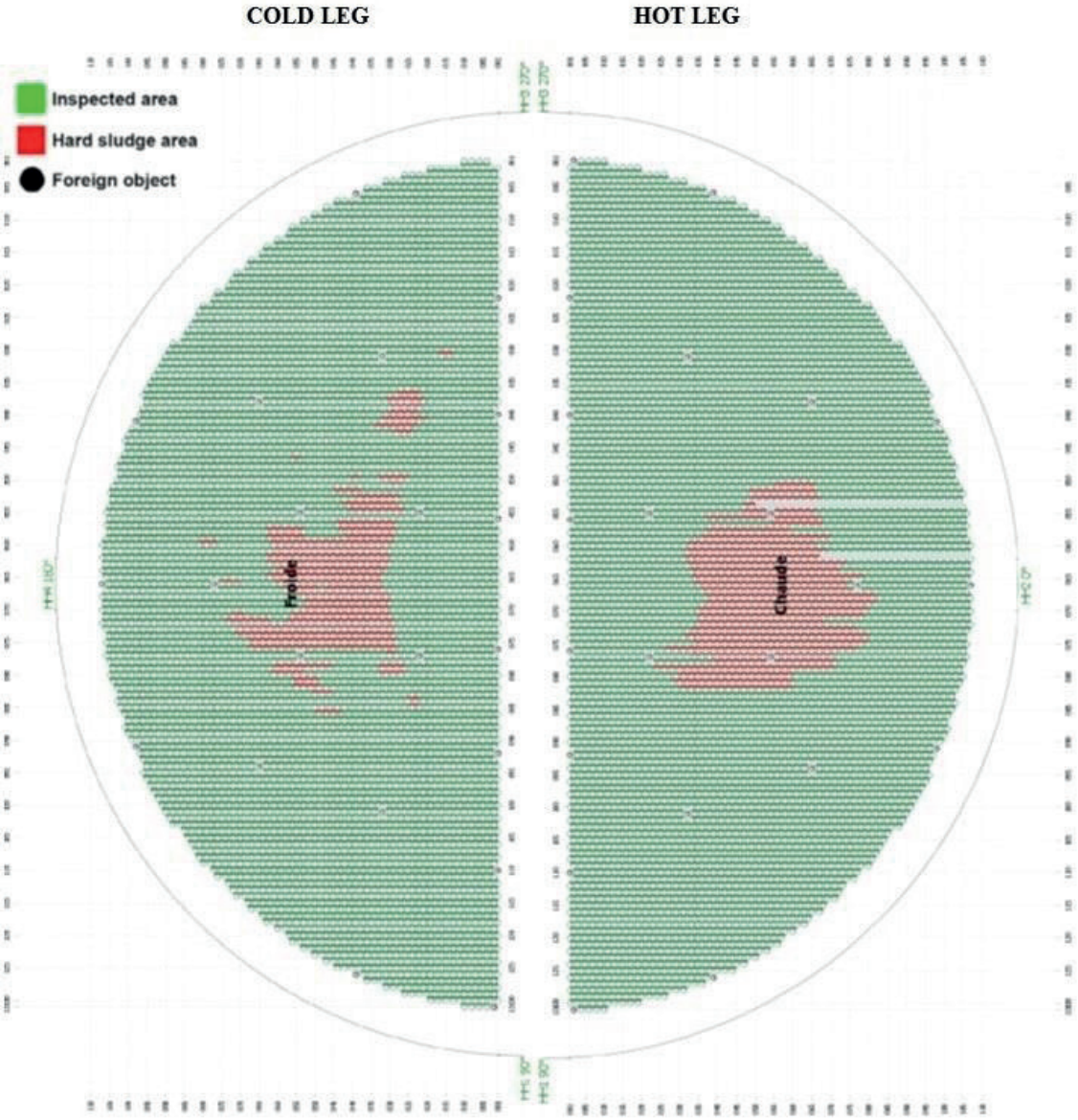

Figure 6: SG1 TV inspection results

4.2 SG2 results after first Sludge Lancing

In 2018 outage, NEK carried out the first SL on SG2 with a TV inspection, followed by IBL, second SL and another final TV inspection. During the first TV inspection, three old foreign objects were found in addition to a new one. It was believed that the new one would be destroyed during the IBL phase which was exactly what happened. In the cold leg, the hard sludge area is difficult to characterize. Only hard sludge with small elevations is noted.

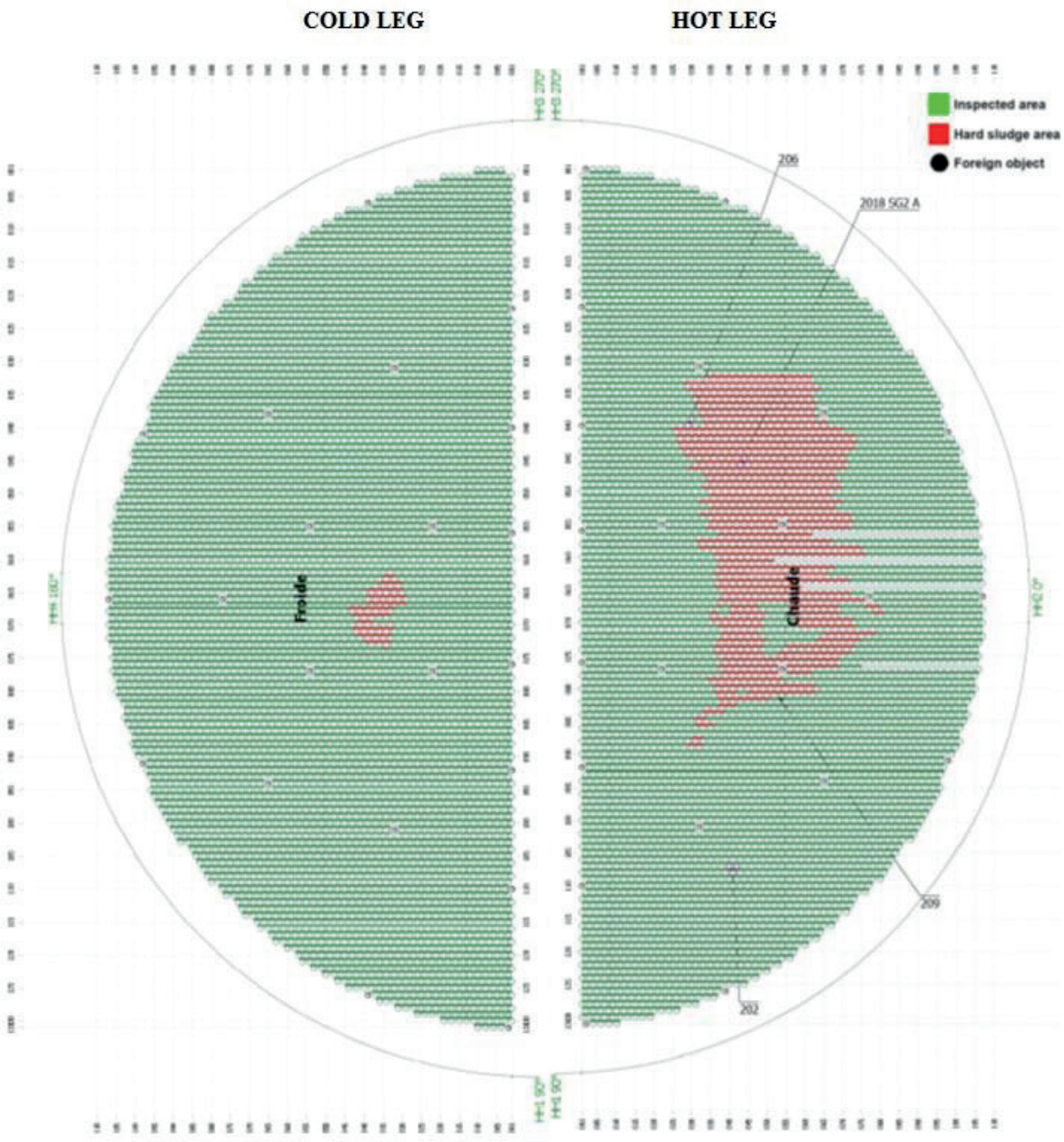

Figure 7: SG2 TV inspection results after the first SL

4.3 SG2 results after Inner Bundle Lancing

After the IBL phase in SG2 in both legs, the sludge height has decreased. IBL is oriented to hard sludge area only, so the second TV inspection only checks those areas. Two old foreign objects remained in place, one (new one) was destroyed as expected but one old object moved to another location. It will be closely monitored in the future.

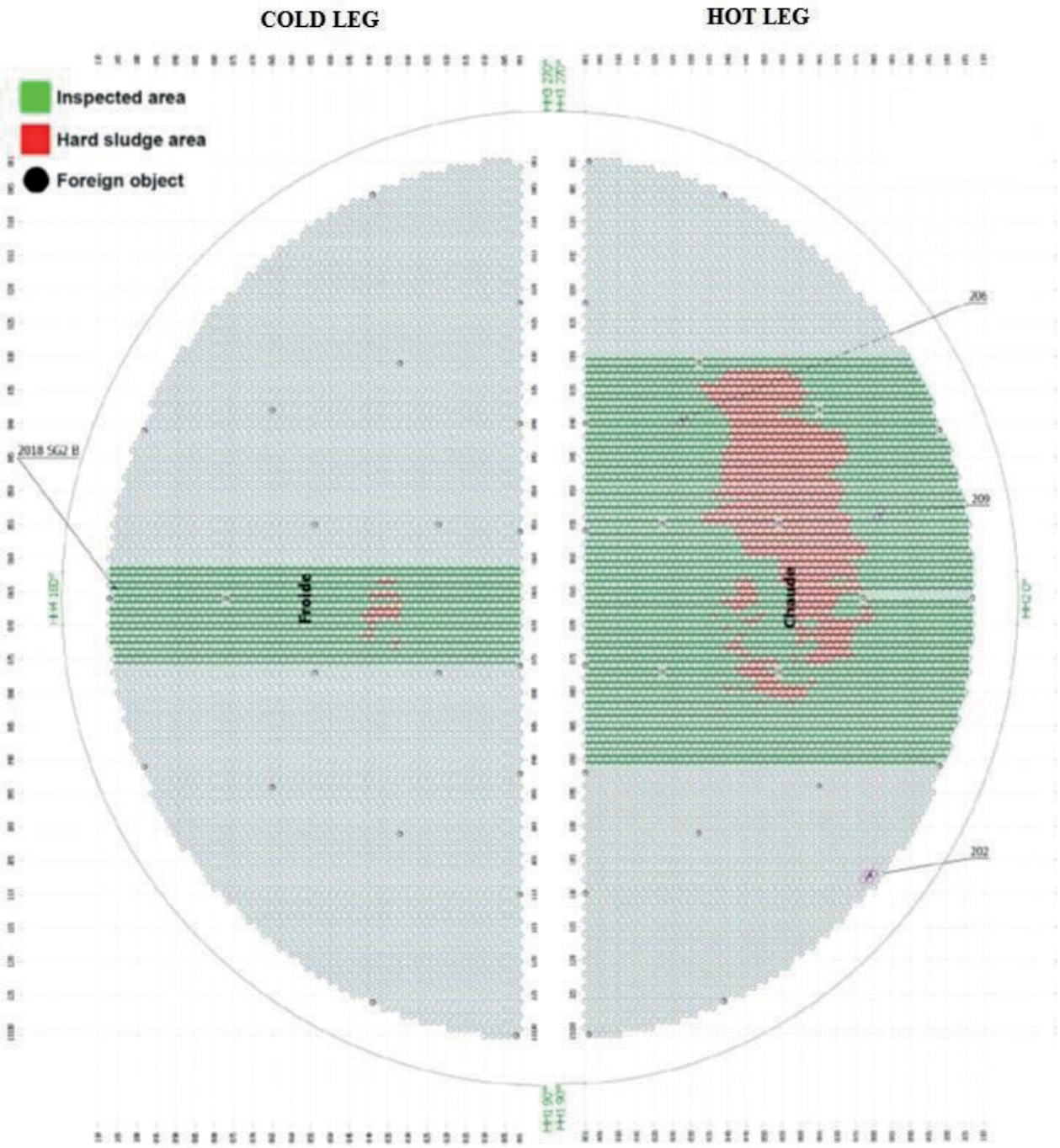

Figure 8: SG2 TV inspection results after IBL and second SL

4.4 Amount of sludge removed from the SG's at NEK in 2018

The weighing is performed after each SL for each steam generator separately. The process is strictly monitored, photographed, and noted. The scale is verified, calibration sheets are provided. The filter is weighed prior to start of operations and again at the end. The results on the amount of sludge are reported to Chemistry Department and the samples of the sludge are taken to determine the structure and to check the radiochemistry.

After the SL on SG1, a total of 40.7 kg of wet sludge which equals to 30.2 kg of dry sludge was removed.

On SG2 after the first SL, a total of 44.2 kg of wet sludge which is approximately equal to 33.0 kg of dry sludge was removed and after the IBL and second SL additional amount of 24.1 kg of wet sludge equal to 18.2 kg dry sludge was removed.

The total amount of the removed sludge was 109.0 kg (wet) which is equivalent to 81.4 kg of dry sludge.

Currently, three stuck foreign objects, which are closely monitored every outage, are inside SG2.

5 CONCLUSION

Steam generators are safety related components that are required to operate during normal, abnormal and emergency conditions. During normal power operation steam from steam generators is supplied to the turbine at a pressure of 66.9 kp/cm^2 and a flow of 3931 t/hr. During shutdown conditions, they are a vital component in decay heat removal process. In case of a station blackout, decay heat removal is ensured by maintaining auxiliary feedwater flow to both steam generators with auxiliary turbine driven feedwater pump. Additionally, steam generators act as a third barrier for preventing radioactive releases into the environment. Due to this the cleanliness and operability of steam generators is vital for safe operation.

Performance of SL and IBL cleaning methods, minimize the growth rate of sludge deposits on top of tube sheet. The benefit is mostly observed in the reduction of sludge height and area surface. Based on previous experience, each time the IBL is performed, the amount of sludge removed from steam generator increases by up to 40%. Therefore, it can be concluded that periodic IBL and SL should be performed each outage to decrease and remove sludge deposits in steam generators, therefore ensuring a longer operational lifetime of steam generators.

REFERENCES

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[2] SUEZ "End of intervention report" Reference number: 18 RFI EC 001