20 Years of Experience in Steam Generator Replacement (SGR)

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Abstract. Framatome ANP having more than 20 years of experience in the Replacement of Steam Generator components, specializes in major component replacements and offers a total package of replacement services to the commercial nuclear industry. Starting with the first Steam Generator Replacement (SGR) in the Nuclear Power Plant Obrigheim/Germany in 1983, Framatome ANP has been involved in over 50% of SGR projects worldwide, becoming the industry leader in turn-key SGR projects both in North America and Europe. Full range replacements have been performed in 40 Nuclear Power Plants with a total number of 112 replaced SGs including the SG types designed by W, CE, B&W and Framatome ANP. Following is an overview of the Framatome ANP approach to SGR projects. Various aspects of project planning, engineering, management, licensing, qualification of personnel and techniques used including outage implementation will be presented.

1. Introduction

Nuclear Power Plants (NPP) were designed in the past to operate for 30 to 40 years. Therefore the consideration of lifetime extension of the existing NPPs is more and more the target of an economical plant management, reducing operating and maintenance costs. This includes the replacement of the components.

One of the main components of the primary circuit in a Pressurized Water Reactor is the Steam Generator (SG). The replacement of SGs can prevent unscheduled outages, maintaining efficient plant operating conditions to extend service life and enhance safety. The technical and economic feasibility of replacing this component has been demonstrated by the SG replacements performed worldwide.

1.1. Dimensions and Loop Arrangement of Steam Generators

The overall dimensions of a SG differ due to the plant power output, the number of SG components and the SG designer. Typical dimensions of Steam Generators vary in the length from 19000 to 21000mm with a steam dome diameter of more than 4000mm. The average weight of one unit is between 200 and 450tons and generally the replacement SG is about 20 to 30 tons heavier than the old SG as a consequence of the power upgrading by increasing the heat transfer zone. The quantity of SG units per plant differs from two (2) to eight (8).

The SGs are normally installed vertically, however some plants have horizontally lined up components.

Typical arrangements of piping and components inside a loop are shown in Figures 1 and 2.
Legend:

1 = Loop Entrance  
2 = El. +18,0m  
3 = Stairway to El. +21,0m  
4 = Pressurizer  
5 = Residual Heat Removal Line  
6 = RCP\(^1\) - Hot Leg  
7 = Surge Line  
8 = Steam Generator  
9 = El. +21,0m  
10 = RCP\(^1\) - Crossover Leg  
11 = RCP\(^1\) - Cold Leg  
12 = Safety Injection Line  
13 = Accumulator Injection Line  
14 = Reactor Coolant Pump  
15 = El. +23,6m  
16 = El. +26,1m  
17 = Spray Line  
18 = Filling Line

\(^1\) RCP = Reactor Coolant Piping

FIG. 1. Typical Loop Arrangement (Example 1)
2. Turnkey Approach

Over the years, Framatome ANP has formed an experienced team of engineers and specialists for the performance of Turnkey Projects including: [1]

- Overall coordination and management
- Engineering, design, design calculation, licensing according to country-specific and/or international codes and standards
- Planning, scheduling, preparation and performance of all construction and outage activities including system tests and commissioning
- Subcontracting, purchasing, personnel & process qualifications and labour management
- Performance of all required tasks (see item 3)

During the last 20 years various methods for SGR’s were developed and applied. In the earlier years a partial replacement was always performed which renewed only the primary section (lower portion with the tube sheet and tube bundle) of the SG. However, this resulted in much more welding on site and lengthened the replacement outage significantly. Therefore techniques were conceived to replace the SG components in one piece. This resulted in a significant reduction of the collective radiation exposure and especially the outage duration.
The typical scope of a SGR project is shown on Fig. 3.

3. Temporary Containment Opening

Comprehensive technical solutions were developed to transport the SGs out/in when

- no equipment hatch is available,
- the hatch diameter is too small for the component overall dimensions or
- the position of the equipment hatch is not suitable for SG transportation purposes.

Temporary openings have been created in all types of containments including post tensioned ones with tendons (see Fig. 4) [2]. For the first time in the world in 1989, a temporary opening was cut into the containment building wall, at NPP Ringhals 2/Sweden. Framatome ANP’s scope consisted in related engineering and site performance.

The vertical lifting of the SGs via temporary openings in the Containment Dome with separate cutting of the Steel Liner and Concrete Containment has proven to be an effective method in several SG Replacement projects.
4. **Rigging/Lifting of Steam Generator**

Special solutions have been provided in the case that a lifting device is necessary outside the Containment (see Fig. 5) or if the polar crane does not have sufficient lifting height or trolley capacity.

In front of the equipment hatch or the temporary Containment Opening, the SGs are moved into a tilting device which allows them to be turned into a horizontal position orientation onto transportation saddles (see Fig 6). Another possibility depending on the elevations inside the Containment Building, is to turn the SGs “in the air” hanging on two temporary gantries installed on top of the Polar Crane.

Framatome ANP has various solutions if the areas for the lifting/lowering are very narrow. In Fig. 5 the lowering of a 220t and 19m long SG is shown. The distance from the component to the neighboring building walls during the entire lifting height is at maximum 200mm on each side.

All applied solutions consider ASME and national regulatory codes. Framatome ANP has prepared the necessary licensing documentation in close cooperation with the plant utility.
FIG. 5. Lifting the SG with Temporary Outside Hoisting Tower

FIG. 6. Different SG Rigging Sequences
5. Activities at the Reactor Coolant Pipes (RCP)

Optical measurement

Because the chosen two-cut method on the RCP (one cut on each primary nozzle) and the very fine fit up tolerances of the pipe ends fitted to the nozzles required for the narrow gap welding process, precision survey methods must be applied, such as:

- Photogrammetry
- Laser tracking
- Electronical theodolites

RCP - Clamping and Fit up (Fig. 7)

Prior to cutting the RCP, each Hot Leg and Crossover Leg is blocked in its original position by using a clamping device equipped with hydro jacks. Each hydraulic unit is equipped with fine scale manometers to monitor the pressure with respect to the displacements. The hydro jacks are not only used for blocking the system; they are also used for the pipe displacements which are necessary to minimize pipe stress which would otherwise be induced by the weld shrinkage and the fit-up of each pipe end to the relevant nozzle. The device is designed to cover all moving directions (x-y-z axis).

The allowable displacement with respect to the forces are verified by several intensive calculations [3].

![Clamping Device on XOL - LEG](image)

FIG. 7. Clamping Device on RCP – Hot- and Crossover Leg

RCP- Cutting and Machining (Fig. 8)

A mechanical process is used for RCP-cutting and machining due to the ALARA principle. The cutting machines are mounted and aligned on the RCP pipes. The machines are driven by hydraulic power units. Both cuts - Hot Leg and Crossover Leg - are performed simultaneously and in two steps.
Step 1: Cutting up to ~95% of the wall cut with a blade cutter. The re-indexing of the blade cutters depth is achieved automatically at each rotation.

Step 2: Replacement of the blade cutters by cutting wheels and cut completion. The cutting wheel has the advantage, that no debris is produced, which can enter the primary system. The machining of the remaining pipe ends is performed after decontamination and optical measurement. The beveling machines are centered in the pipes and adjusted with a reference ring, which is aligned by optical measurement.

The machines are equipped with spherical ball joints and mechanical jacks to allow fine adjustments. Both joints on each loop are machined in parallel and with great accuracy. The weld edge geometry is given by the gas tungsten arc (GTA) narrow gap welding process. [4]

![FIG. 8. Cutting of RCP and Machining/Bevelling of RCP](image)

RCP – Pipe End Decontamination (Fig 9)

After removal of the old SG’s, the pipe end decontamination takes place in order to lower the dose level for the following activities like optical measurement, machining, welding etc.

The measurements on the open pipe ends generally showed a contact radiation dose level inside the pipes between 60 – 130 mSv.

For the decontamination, a mechanically abrasive (sandblasting) process is selected. This process produces less waste than a chemical process. The results between both methods are comparable.

Prior to starting the process a leak tight seal disc is inserted into the pipes to avoid blasting media from entering the reactor coolant system. Then the equipment is mounted on the pipe end, consisting of: front box with a clamping device and the manipulator with rotating nozzles.

A compressor supplies sufficient air capacity of 10 m³ per minute and with the required pressure of 8bars.
Decontamination is performed in two steps:

*Step 1:* Blasting with an electro-corundum to remove the oxide layer with high radiation.

*Step 2:* Blasting with glass beads to improve the superficial stress conditions and to smoothen the surface.

A closed-circuit system with negative pressure is used to avoid aerosols. The decontamination depth is ~ 500mm. After decontamination, a shielding plug is inserted into each pipe end to separate the decontaminated area from the non-decontaminated area.

An average dose reduction factor between 40 – 60 is achieved.

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**FIG. 9. Decontamination of RCP Hot Leg**

RCP – Welding (Fig. 10)

The welding of the remaining pipe ends to the SG-nozzles is performed with a remote controlled mechanized GTA process with a special narrow gap weld geometry.

Hot Leg and Crossover Leg are welded simultaneously. By the time the last SG is fitted up four (4) welding machines are operating in parallel. Welding is usually performed in 2 x 10h shifts, 4 hours are needed to cool down the pipes.

After welding completion and weld built up, the joints are ground mechanically with a special geometry for ultrasonic testing examinations. The grinding is followed by the required non-destructive examinations.
6. Secondary- and Auxiliary Piping

Main Steam Line (Fig. 11)

A section of the main steam line is removed only for clearance purposes for SG-Rigging. The MS-Restraint is also removed due to the fact that the auxiliary cranes are installed in that location. As soon as the new SG is back in place the existing pipe spool is machined and re-welded followed by NDE. When the relevant aux. crane is dismantled, the restraint is reinstalled.
Main Feedwater Line (Fig. 12)

The old SG’s are sometimes equipped with a preheater. The FW-nozzle is located closely above the tube plate. Normally, the new SG’s do not have preheaters and the feedwater nozzle is located in the conical part of the SG, that means approximately 8 m higher than the existing one.

**FIG. 12. Feedwater Line**
Due to this fact the feedwater line is rerouted inside the cubicles to connect it to the new nozzle location. Therefore new supports and restraints are also installed.

Sometime due to new piping calculation concepts (leak before break; snubber reduction program) some further modification of the piping systems (not only feedwater) are performed.

**SG – Instrumentation**

Due to the difference of the nozzle locations between old and new SG, the instrumentation lines were usually completely cut out, up to the wall of the cubicle, and rerouted with new tubing and pipe material. Further systems which are usually affected by the steam generator replacement are:

- Auxiliary Feedwater lines
- Blow Down System /Sampling Lines
- Primary drain lines

### 7. **Our Strength for a Successful SGR Project: Customer Oriented Management/Team-Work, Global Experience and Resources**

The important key factor is the team work and intensive cooperation between the plant utility and SGR project team. Highly experienced teams from resources worldwide deliver practice gained from 40 implemented SGR projects since 1983 as well as eight (8) more Steam Generator Replacement outages under contract in 2004-2006.

The project team has to be structured to capitalize on the experience and lessons learned from other past SGR projects recognizing the critical needs for detailed planning, effective command and control and timely project controls to safely and successfully execute the highly complex work evolutions of a major component replacement project. All specialists required for the project-individual task packages form an organisational unit under the co-ordination and responsibility of a project manager who becomes their direct superior for the duration of the SGR project. Processing of projects in this manner has proven extremely effective for the following reasons:

- Communication and information pathways are short and the number of interfaces minimized, allowing the team to respond rapidly to special customer requests.
- Efficiency is high because there is a direct link between work activities and the decision-making process within the project team.
- Team motivation is high and team members identify with their assigned task because they are only involved in a single project.

Worldwide highly-qualified and experienced Framatome ANP personnel is available for SGR project management, logistics, site implementation and performance of any required technical tasks.

Figure 13 shows a typical man-power chart for site implementation of a SGR for a 2-loop plant. Also the total outage time “breaker to breaker” of 62 days can be seen.

Framatome ANP, a worldwide commercial nuclear industry leader, brings the expertise of nuclear power plant engineering, manufacturing, and installation of all major Nuclear Steam Supply System (NSSS) components and systems. This extensive nuclear industry expertise, coupled with successful project and labour management of SGR at numerous plants, resulted in quality products for the plant utility. This resulted in continuous improvement of the parameters of the SGR projects. This particularly is valid for reducing collective dose and replacement time (see Figure 14 and 15).
Figure 15 gives the reduction of the replacement time considering only the critical path for an SGR: from the first cut on RCP up to the completion of the RCP-welds and the primary cooling system ready for hydro test, which has usually been performed after refuelling, during the start up phase of the plant.
Framatome ANP has determined that industrial and nuclear safety, observance of pretended schedule and cost frame, extensive risk avoidance and team work are objectives for each SGR project. A successful interface management between Framatome ANP, plant utility and nuclear authority guarantees the compliance with the given objectives.

The Framatome ANP customer-oriented project planning and management processes are best-in-class. Our task planning, risk assessment and mitigation, contingency planning, proficiency mock-up training, work sequence planning and outage schedules are based on past SGR projects and construction industry standards. The company processes allow to develop realistic plan and assure their achievement.

8. SGR References

Framatome ANP has gained comprehensive experience in SGR projects worldwide. Over the years, Framatome ANP has completed 40 SGR turn-key contracts:

- 16 NPPs in USA
- 13 NPPs in France
- 3 NPPs in Belgium
- 2 NPPs in Spain
- 2 NPPs in Sweden
- 2 NPPs in Switzerland
- 1 NPP in Germany
- 1 NPP in Slovenia

and has been awarded contracts for eight (8) further SGR projects in North America and France. In total 112 Steam Generators have been replaced up to now.
In addition to this projects performed under the complete responsibility of Framatome ANP, Framatome ANP participated in many SGR projects performed by others, in delivery of specific technology and equipment, supervision, training and consulting activities, elaboration of general and plant specific studies for NPPs in Japan, Brazil, Canada and Ukraina.

REFERENCES


