Options for Steam Generator Decommissioning

Gregor KRAUSE [a*], Björn AMCOFF [a], Joe ROBINSON [a]

[a] *Studsvik, SE-611 82 Nyköping, Sweden*

**corresponding author:*
gregor.krause@studsvik.de

Keywords: decommissioning, steam generators, waste management, feasibility.

ASTRACT

Selecting the best option for decommissioning steam generators is a key consideration in preparing for decommissioning PWR nuclear power plants. Steam Generators represent a discrete waste stream of large, complex items that can lend themselves to a variety of options for handling, treatment, recycling and disposal. Studsvik has significant experience in processing full size Steam Generators at its metal recycling facility in Sweden, and this paper will introduce the Studsvik steam generator treatment concept and the results achieved to date across a number of projects. The paper will outline the important parameters needed at an early stage to assess options and to help consider the balance between off-site and on-site treatment solutions, and the role of prior decontamination techniques. The paper also outlines the use of feasibility studies and demonstration projects that have been used to help customers prepare for decommissioning. The paper discusses physical, radiological and operational history data, Pro & Contra factors for on- and off-site treatment, the role of chemical decontamination prior to treatment, planning for off-site shipments as well as Studsvik experience

This paper has an original focus upon the coming challenges of steam generator decommissioning and potential external treatment capacity constraints in the medium term. It also focuses on the potential during operations or initial shut-down to develop robust plans for steam generator management.

1. Introduction

Steam Generators are large heat-exchangers of varying designs that are mainly used for generating steam in nuclear power plants. From a decommissioning perspective, most heat-exchangers share a common basic construction of having an outer, substantial shell covering a large quantity of relatively small-bore tubing that has been subject to radioactive contamination. Currently around 220 retired steam generators (SG) of western PWR type are in on-site storage at European Nuclear Plants (NPPs). These numbers of SG will more than double as NPPs are shut-down and go into full-scale decommissioning.

2. Physical, radiological and operational history data are important parameters in order to define possible treatment and transport options

When planning a SG treatment project, it is important to understand the overall radionuclide vector/fingerprint, examples nuclide inventory in treated SGs see Figure 1. In case the SG is foreseen for segmentation and further conditioning this data is necessary in propose to evaluate the radiological inventory and dose rates for the final waste disposal packages.

Also engineering details, drawings, operational history of the SG, that been recorded and documented by the NPP operator, are of great importance for the future segmentation and decontamination activities. Complexity of a typical SG is shown in Figure 2.

Other important factor is to receive the data regarding the number of tube failures over the operating lifecycle. That’s includes the number of plugged tubes and kind of plugs used.

10 years of decay storage

Radioactivity inventory (each SG)	~TBq	*~Ci*	*~%*
Total:	1,1	*30*	*100*
Co-60:	0,74	*20*	*67*
Ni-63, Ni-59, Fe-55:	0,36	*10*	*33*

No decay storage

Radioactivity inventory (each SG)	~TBq	*~Ci*	*~%*
Total:	9	*243*	*100*
Co-58	7,3	197	82
Co-60:	0,8	*22*	*9*
Ni-63, Ni-59, Fe-55:	0,8	*22*	*9*

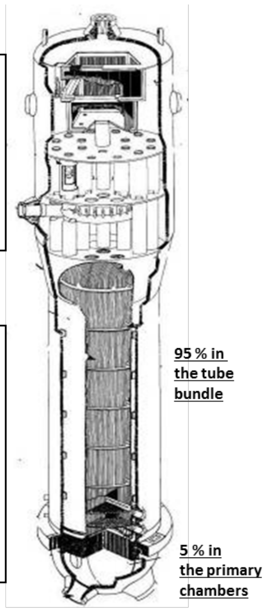

Figure 1: Examples of nuclide inventory in treated SGs: After 10 years storage and no decay.

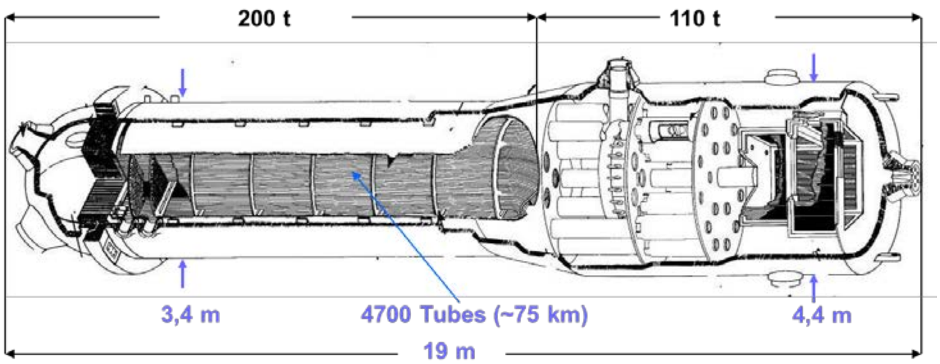

Figure 2: Examples of SG-data (Westinghouse 3-loop design).

3. On-site treatment options including an estimation of cost factors

Site operators have at least two options for on-site treatment of the SGs, although neither option excludes the transportation of radioactive material completely. The residual radioactive waste will have to be removed from site to an appropriate disposal facility.

Option 1 Treatment in the containment

The first option is the treatment within the reactor building (containment). This option is likely feasible when a Chemical Full System Decontamination (FSD) is performed on SGs *in situ*. Without decontamination, the collective dose is likely to be too high and endanger the project. If the treatment of SG in the containment will be on a time critical path the project will be very labor intensive and will have significant conventional and radiological exposure risks related to narrow working areas and utilization of special equipment for segmentation and tube handling.

During SGs treatment inside the containment, the existing waste treatment resources on site may become stretched and waste logistics will become an issue. To accelerate the treatment processes inside the containment the SG shall be segmented in large parts to be evacuated to the external treatment area for further decontamination free release measurements. The support of an external supply chain for material and waste conditioning may become inevitable.

Option 2 Treatment in the local on-site waste treatment center (WTC)

The second option is construction of a new waste treatment center in a suitable existing facility or in new building in connection to the facilities under decommissioning.

As a result of the planning and permitting process for such a facility, as well as the know-how learning curve, it may take a number of years before such a facility is commissioned and operating as expected. There are potential risks that the process may not be effective for the project requirements or additional expenditure be required before the facility is suitable for continuous operation.

Waste treatment facilities can also be used to manage other wastes streams arising during the decommissioning process, and it may be assumed that some facilities are required on-site. However, to accommodate SGs, larger size reduction facilities will have to be built and equipped in order to undertake specialized logistics, heavy lifting and cutting and meeting all appropriate standards and regulatory requirements for safety and environmental aspects.

4. Pro & Contra factors for on-site treatment

1 Treatment in the containment

Advantages	Disadvantages
- Lower capital cost than new facilities - No external SG transport necessary. - Possibility to utilize own staff for segmentation - Large SG segments can be removed for decontamination and free-release measurements	- Lack of working space in the containment. - Expected high initial cost of learning and methodology development. - Blocking of other decommissioning activities. - Long treatment time inside the containment. - Uncertainty regarding the total costs. - Costs linked to extended, total decom-missioning time and delayed site release. - Significant conventional and radiological exposure risks. - Increased regulatory requirements. - Requires external material and waste buffer storage. - Extensive measuring program for free releasing of SG parts - Time critical activity if site release date is planned

2 Treatment in a local waste treatment center, WCT

Advantages	Disadvantages
- Only short on-site SG transport distance. - Equipment available on the market. - Early SG removal means limited interferences with other dismantling activities in the containment. - Large SG segments can be sent for free release measurements. - Early site release date. - Utilization of own staff for segmentation.	- Capital cost for build & equipping facilities - Time for permitting and licensing - Expected high initial cost of learning and methodology development. - SG removal from the containment. - Extensive measuring program for free releasing of the SG parts.

5. Options for off-site treatment

There are at least three main options for off-site treatment of the SGs.

Option 1
Direct disposal of the SG as an entire component or disposal of the tube bundle part only which requires separation of the steam dome.

Option 2
Segmentation of entire SG and packaging in suitable packages for direct disposal.

Option 3
Treatment with the target to minimize the secondary waste volumes for disposal by melting, free-release and recycling. About 15-20 % of the SG weight corresponding to 10-15 % of the initial SG volume will be sent for disposal based on data from 13 SG treatment projects.

Option 2 and 3 will depend on the results of chemical pre-decontamination described below.

6. Pro & Contra factors for off-site treatment

1 Disposal of the SG as an entire component

Advantages	Disadvantages
- Fast and reliable process. - Reduces or removes on-site/project risks related to time plan and available space. - Limited conventional and radiological exposure risks.	- Large volumes of secondary waste for disposal. - Not in line with general environmental policies and guidelines. - Restrictions on transportation options - Requires repositories that accepts large components for direct disposal

2 Segmentation and packaging in suitable packages for direct disposal

Advantages	Disadvantages
- Fast and reliable process. - Reduces or removes on-site/project risks related to time plan and available space. - Limited conventional and radiological exposure risks.	- Large volumes of secondary waste for disposal. - Not in line with general environmental policies and guidelines. - Restrictions on transportation options

3 Treatment to minimize secondary waste for disposal by melting and recycling

Advantages	Disadvantages
- Proven, fast and reliable process. - Full cost control for the transport and treatment. - Small volumes of secondary waste for final disposal. - In line with general environmental policy and guide lines. (Waste hierarchy & Best Available Technique). - Reduces or removes on-site/project risks related to time plan and available space. - Limited conventional and radiological exposure risks.	- Restrictions on transportation options. - Limitations on SG total activity inventory with pre- decontamination or decay storage required.

7. The role of prior chemical decontamination

Successful system decontamination is often a requirement in order to enable external transports and off-site treatment of SGs.

The decontamination factor (DF) for the chemical decontamination e.g. the residual radioactivity is also strongly related to the feasibility for the final treatment on-site. High DF reduces the collective dose during the segmentation activities and during the conditioning of the waste packages generated during the treatment of the SG. Low dose rates on the packages for secondary waste eliminate necessity for special transport casks or additional shielding to fulfil regulation for transport to the interim storage or final disposal facilities.

On occasions where SGs have been in storage for many years, decay storage of 20-30 years is sufficient to meet the requirement for Studsvik's treatment and recycling method for off-site treatment.

8. **Planning for off-site shipments**

There are advantages in removing and transporting the SGs to the external treatment facilities. In general this option has the benefit of utilizing proven processes for the size reduction and treatment of large, contaminated components in designated facilities that have been designed and developed for the purpose.

All options for on-site waste treatment center- and external- treatment requires SG dismantling and its removal from the containment and positioning the SG on the support saddles. Thereafter the SGs can be transferred directly to a heavy transport trailer for immediate removal from the site.

Any options which involve movement of the SGs over long, transboundary distances will require pre-studies to investigate the licenses, means of transportation, transportation routes, etc.

For licensing of domestic and international transport several authorities have to be involved such as:

- Transport authorities
- Nuclear authorities
- Harbour authorities
- Environmental authorities
- Other country specific authorities and organisations

Each decontaminated SG is a sealed unit and can be transported under ADR regulation as IP2 contaminated object without additional packaging. For not decontaminated SGs, coming from the on-site storage, additional shielding of the SG tube section may be required for the transport.

For SGs, with the activity inventory above the SCO limits, the transport has to be carried out according to *special arrangements* for which specified approval of the package design including issuing of a large component *design approval certificate* is required. The entire large component has to be qualified as IP-2 (industrial package) to verify the package integrity in case of accidents during the transports. This kind of qualification includes several simulations of horizontal and sloped drop tests and other possible accident scenarios.

Below are listed most important preparation phases for transport of large components which also has to be evaluated in pre-studies for SG shipments to the off-site treatment facilities:

- Site works
- Radiological surveys
- Capping and sealing of penetrations
- Additional shielding
- Painting or wrapping of the components
- Structural surveys and transport justification
- Design and manufacture of new, component specific transportation saddles
- Documentation for safe lifting
- Survey of the transport route
- Heavy transport
- Support to regulatory organisations and stakeholder engagement
- Permit and applications

9. Studsvik Experience

Studsvik has in several SG treatment projects treated 13 full size SGs.
9 x 300 Mg and 4 x 165 Mg each demonstrates that the SG may be shipped as 'whole 'component, for external treatment.

The process for recycling SG's was developed by Studsvik during the last decade. The driving force for treatment of those components was primarily to reduce the waste volume for final disposal, although there are other benefits such as reduction of on-site/project related risks as well the elimination of a time critical project during on-going decommissioning. The total time for the decommissioning project can be significantly reduced by sending the large components off-site for treatment.

For the SGs and other large component projects and studies Studsvik has demonstrated that the transport routes from several European, Asian and North/South American countries are open or can be opened when necessary.

SGs received at the treatment facility are characterized, decontaminated and size reduced. The contaminated tubing material is fragmented with the purpose to reach the maximum volume reduction for final disposal. Other SG parts are decontaminated and melted in an induction furnace. The homogenized metal is then cast into ingots. The ingots samples are sent for analysis to verify the radiological inventory for free-release and recycling.

The SG's treated resulted in recycling of a total 80-85% of the original tonnage usually suitable for future unrestricted free-release and recycling. The remaining 15-20% is conditioned for return as secondary waste for disposal.

The SG treatment setup, see Figure 3, incl. following main handlings steps below are applied during treatment of Steam Generators:

- Transportation, see Figure 4
- Disconnection of and segmentation of the steam dome
- Decontamination and segmentation of the water chambers
- Dealing with plugged tubes, see Figure 4
- Decontamination and segmentation of the tube bundle
- Segmentation of the outer shell
- Decontamination and segmentation of the tube plate
- Melting of the material from the steam generator, see Figure 4
- Free-release for further recycling
- Waste conditioning

Each of those steps has to be carefully planned, prepared and executed taking into consideration the SGs technical, radiological data and operational history.

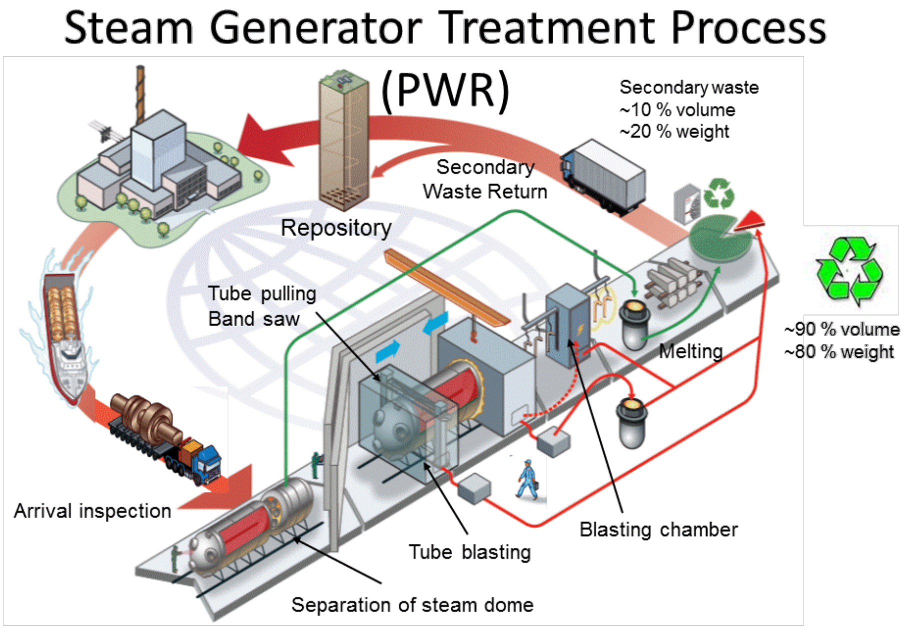

Figure 3: Setup for treatment of SGs.

The acceptance of SGs for treatment in Studsvik is based on:

- dose to personnel
- the ability to transport the SGs to Studsvik respecting ADR regulations/special arrangement
- the secondary waste management without jeopardizing any radiological limits for surface dose rates on the secondary waste packages

The radiological acceptance criteria’s are:

- Dose rate: < 200 µSv/h on the external SG surfaces
- Co-60 activity: < 0,5 TBq in each SG

SGs fulfilling those threshold criteria’s can be transferred to Studsvik for treatment and the secondary waste return transport can be managed properly.

Figure 4: Transport Tube pulling Melting

10. Conclusion

The nuclear industry's demand for environmentally sound and cost effective management of all kind of large components is becoming increasingly important. The upgrading programs as well as the strategy for immediate decommissioning applied by an increasing number of utilities are creating additional demand for effective off-site waste treatment facilities.

Through systematic development of treatment technologies and waste conditioning methods Studsvik has established a new technological sector for treatment of Steam Generators.

The off-site treatment of larger components have a number of advantages including the safety benefits and cost savings by avoiding the need for the bespoke size reduction and construction of on-site waste treatment facilities for large components. For comparison of required net volume for direct disposal of 178 SGs vs. net volume of waste generated from conditioning of those SGs see Figure 5.

There is obvious and significant safety, environmental and cost benefits from undertaking this type of work in purpose-built facilities. These advantages likely outweigh the inconvenience and cost of transporting the large components.

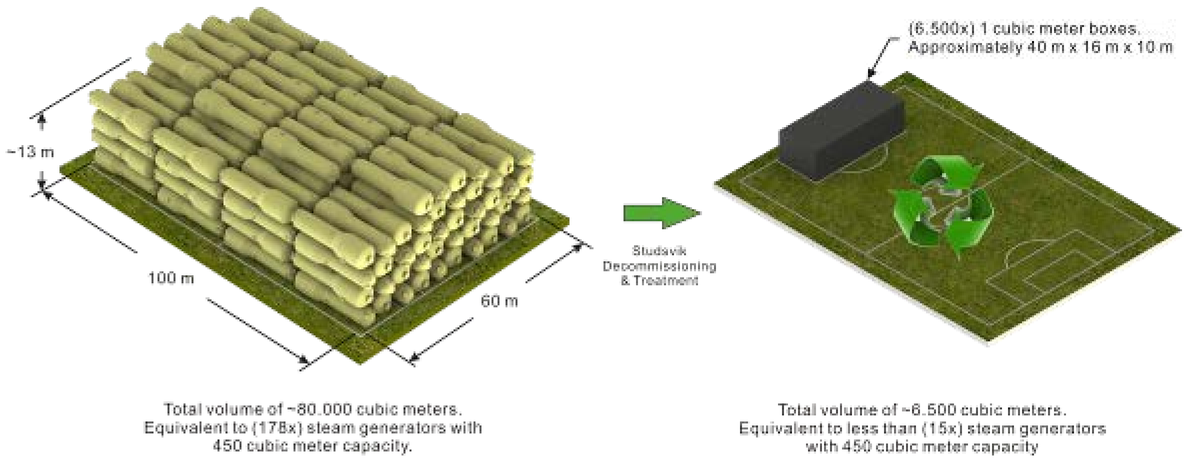

Figure 5: 178 SGs: Net volume for direct disposal vs. net waste volume after treatment.