Transport of French PWR Steam Generators to Very Low Level Waste Disposal – 15203

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ABSTRACT

When considering the complexity of IAEA nuclear transport regulations, the transport of a Steam Generator (SG) in one unpackaged block from a dismantling plant to a nuclear waste disposal is a challenge. The choices made, the difficulties encountered and the feedback that has been learnt from it are described. The disposal of decommissioning waste requires taking into account not only the constraints of acceptance of the repository but also the specific constraints of transportation from the dismantling plant to the final disposal site. In France, these criteria and regulations are respectively under the supervision of the French National Radioactive Waste Management Agency (ANDRA) and the French Nuclear Safety Authority (ASN). In the course of the dismantling of the EDF PWR plant Chooz A, the four decontaminated SGs were shipped to the ANDRA Very Low Level Waste (VLLW) repository. After removal, the SGs were decontaminated, allowing them to attain the criteria of VLLW and thus be accepted by the ANDRA. However, to transport these decontaminated SGs as single unpackaged blocks, it was necessary to ensure compliance with the Surface Contaminated Object SCO-I regulation criteria. For this, transport safety files were written and surface contamination and radiation criteria checked. One of the four SGs had to be decontaminated again and another one had to be transported under special arrangement. Due to the exceptional nature of the transportation, specialized means of transport and stowage were also studied.

INTRODUCTION

France’s nuclear power consists of 58 Pressurized Water Reactors. EDF is the only operator of the French nuclear power plants. EDF also has a first generation decommissioning plan involving different types of reactors: Heavy Water Reactor, Natural Uranium and Gas Cooled Reactor and Fast Neutron Reactor. Chooz-A is the first Pressurized Water Reactor (PWR) of the French decommissioning plan.

Located in the Ardennes on the banks of the River Meuse, the Chooz A nuclear power plant (NPP) was the first PWR built in France (1963). With a power output of 305 MW, it produced electricity from 1967 until 1991 (38TWh). Chooz A NPP was permanently shut down in 1993 and the fuel was completely removed. The unusual feature of this NPP is its location in a cave.

The complete dismantling decree was published in September 2007. According to this decree, the dismantling is spilt into 3 main steps:

- 1st step: dismantling of all the nuclear equipment (2008 to 2015)
- 2nd step: monitoring the decrease of the tritium ratio (2015-2017)
- 3rd step: dismantling of the monitoring equipment and infilling of the underground buildings with concrete

In France, a single public body is in charge of the long-term management of all radioactive waste, under the supervision of the Ministry of Ecology, Energy, Sustainable Development and the Sea, and the Ministry of Research: The National Radioactive Waste Management Agency or ANDRA. ANDRA has defined different classes of nuclear waste in order to assess the radiological risk. Chooz-A SGs have been decontaminated in order to reduce their activity levels and be able to store them in one piece, at the ANDRA Very Low Level Waste (VLLW) repository.

In 2010, the dismantling of the circuits connected to the reactor vessel began. In April 2012, the four steam generators were extracted and prepared for decontamination. The sequence of events leading to shipping was the following:

- Isolation of secondary piping (discharge steam and water supplies) of the SG
- NPP cutting
- SG extraction (a tough operation considering the lack of space in the cave, as the SGs were first introduced in 1965 and the last floor then built around them)
- Decontamination
- Radiological measurements

These different operations allowed the ANDRA storage criteria to be attained. The SGs had then to be shipped as single units unpackaged to the Very Low Level Waste (VLLW) repository.

The demonstration of transportability of the SGs with respect to transport regulations and the transport itself are as follows. First, the SGs and the operations and measurements they were subjected to are described, then, regulatory criteria which allowed categorization of the SGs are stated, and finally, the measures applied to comply with regulations and ensure a safe transport are described along with any difficulties encountered.

DESCRIPTION

Steam Generator Physical Description

The design of the steam generators is shown in Fig. 1. On a PWR, the steam generators are heat exchangers designed to produce the steam for the turbine in the secondary circuit from the heat of the primary circuit. The lower part of the steam generators is connected to the primary circuit by the primary coolant inlet and outlet. The upper part of the steam generators is connected to the steam secondary circuit by the water feed inlet and the steam outlet. The outer shell of the steam generators is pierced by several orifices such as primary and secondary manholes, hand holes and connections. The carbon steel outer shell thickness is 50 to 95 mm.

The heat exchange is made through the tube bundle. 1 662 U-shaped tubes (internal diameter 16.5 mm) are connected to the tube sheet. The primary coolant circulates through the channel head, through the tube sheet and within the tube bundle.

Physical data of the steam generators are given in Fig. 2 and TABLE I.

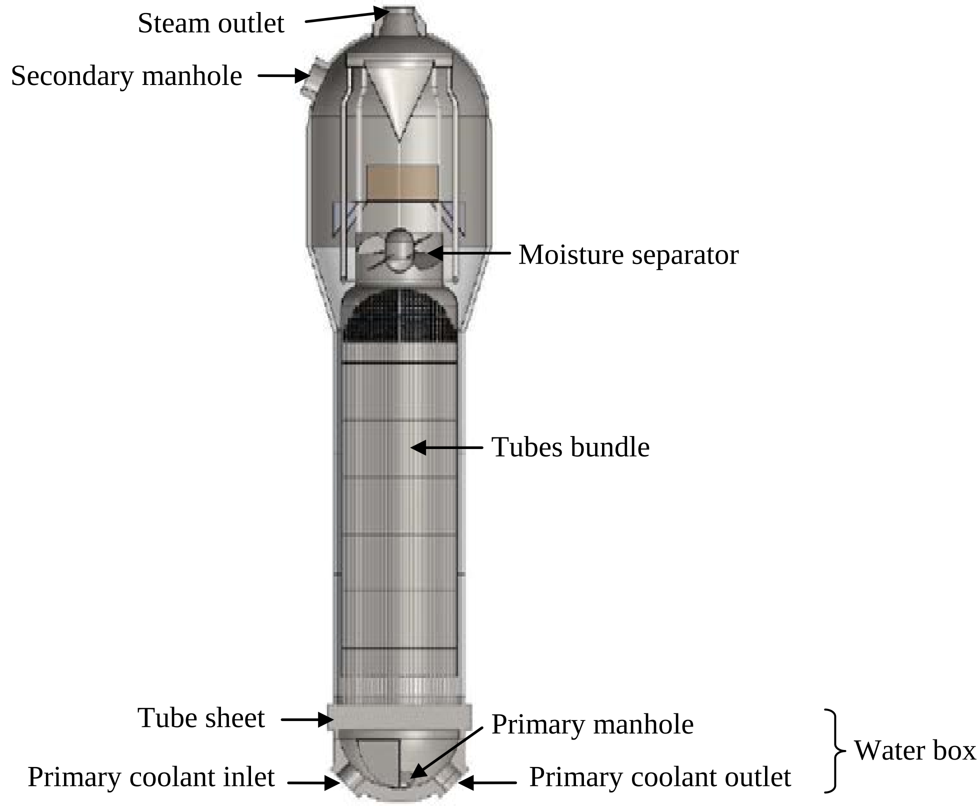


Fig. 1. Cross-section of a PWR steam generator.

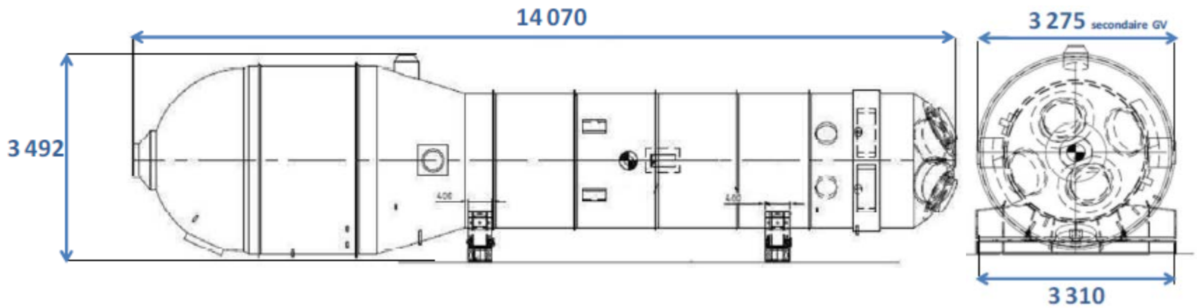


Fig. 2. Outer dimensions of the steam generators.

TABLE I. Physical data of the steam generators.

Characteristics (without stowage system)	**Unit**	**Values**
Mass	kg	120 000
Total length	m	14.070
Width (with supports)	m	3.310
Height	m	3.492

Operations and Measurements Undergone by the Steam Generators

Once extracted, the SGs and their sealed tubes (see Fig. 3) were decontaminated in order to remove enough contamination to reach the ANDRA Very Low Level Waste (VLLW) activity levels criteria:

- The primary part of the SGs was decontaminated by means of the AREVA CORD© (Chemical Oxidation Reducing Decontamination) process (see Fig. 4)
- The sealed tubes were mechanically unblocked and decontaminated mechanically (by blasting)
- These tubes were then decontaminated chemically with Cerium (only for SG1, SG3 and SG4)

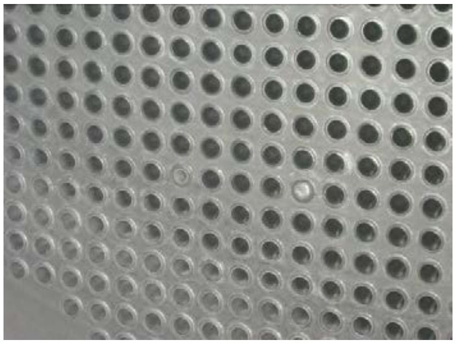


Fig. 3. Sealed tubes.

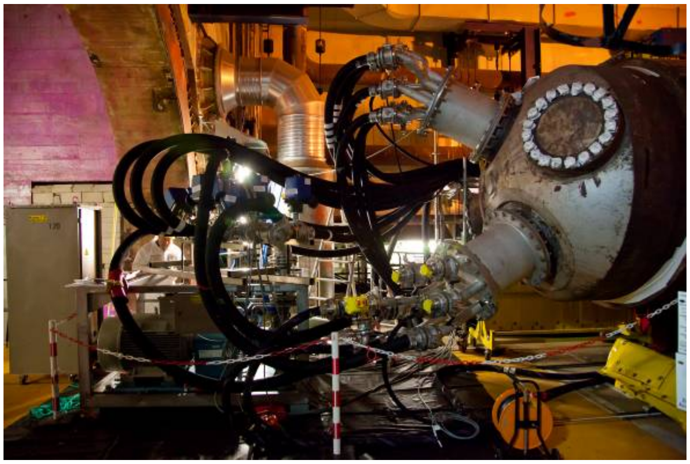


Fig. 4. Connexion of a SG to the AMDA© (Automated Mobile Decontamination Appliance) deployed by AREVA NP to apply the CORD© process.

After decontamination, three types of radiological measurements were performed on the Chooz A SGs:

- Measurement inside the tubes using a probe, and integration of the measurement of gamma-emitting surface activity
- External measurement with a characterization gamma chain
- Samples of metal taken from inside the tubes and sent to laboratory

The SGs decontamination processes and measurement methods are detailed in [1], [2] and [3].

Regulation: SCO-I Transport Criteria

The SGs are considered as Surface Contaminated Objects (SCO), namely solid objects which are themselves not radioactive but have radioactive material distributed on their surfaces. For the SCO objects, the IAEA transport regulations [4] and its French equivalent [5] impose the following limits for road transportation:

- The radiation level at any point on the external surface of a package is limited to 2 mSv/h and the external radiation level at 3 m from the unshielded object should be lower than 10 mSv/h
- The activity should be lower than 100 A2

Transport regulations allow the transport of SCO objects unpackaged under the following conditions:

- The object should respect the SCO-I criteria presented in TABLE IV:

TABLE IV. SCO applicable limits according to [5].

SCO type	**Particles**	**Accessible surface**		**Inaccessible surface**
		Non-fixed contamination	***Fixed contamination***	***Fixed and non-fixed contamination***
SCO-I	β, γ	4 Bq/cm^2	4×10^4 Bq/cm^2	4×10^4 Bq/cm^2
	α	0.4 Bq/cm^2	4 000 Bq/cm^2	4 000 Bq/cm^2
SCO-II	β, γ	400 Bq/cm^2	8×10^5 Bq/cm^2	8×10^5 Bq/cm^2
	α	40 Bq/cm^2	8×10^4 Bq/cm^2	8×10^4 Bq/cm^2

- The inaccessible non-fixed contamination, if higher than a limit value, should be confined

DISCUSSION

Dose Rate

The dose rate values obtained after decontamination were far lower than the regulatory limits, as shown in TABLE II.

TABLE II. Dose rate on contact of the SGs after decontamination (activities 01/01/2014).

SG	**Average dose rate**	**Maximum dose rate**
SG1	A few µSv/h	61 µSv/h
SG2		15 µSv/h
SG3		30 µSv/h
SG4		40 µSv/h
SCO Limits [5]	2 mSv/h at contact	

Activity

The activity values obtained after decontamination were far lower than the regulatory limits, as shown in TABLE III.

TABLE III. Activity of the SGs after decontamination (activities 01/01/2014).

SG	Activity
SG1	0.05A2
SG2	0.06 A2
SG3	0.12 A2
SG4	0.11 A2
Limit for unpackaged transport [5]	100 A2

Contamination

The radiological state of the four SGs measured in the controlled area after decontamination is given in TABLE IV and TABLE V. The CORD© process allowed the initial contamination to be decreased by 1 000 times.

TABLE IV. β, γ contamination of the SGs after decontamination, in Bq/cm^2 (activities 01/01/2014).

SG	Accessible surface		Inaccessible surface
	Non-fixed contamination	***Fixed contamination***	***Fixed and non-fixed contamination***
SG1	< 0.4	1	8 700
SG2	< 0.4	10	1 tube at 9.51 × 10^4
SG3	< 0.4	10	3.1 × 10^4
SG4	< 0.4	< 10	2.8 × 10^4
SCO-I Limits [5]	4	4 × 10^4	4 × 10^4
SCO-II Limits [5]	400	8 × 10^5	8 × 10^5

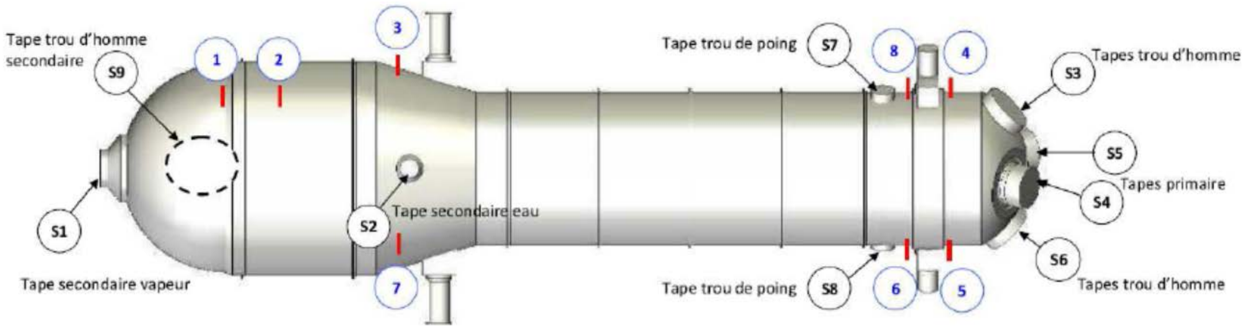
TABLE V. α contamination of the SGs after decontamination, in Bq/cm^2 (activities 01/01/2014).

SG	Accessible surface		Inaccessible surface
	Non-fixed contamination	***Fixed contamination***	***Fixed and non-fixed contamination***
SG1	< 0.04	0.04	240
SG2	< 0.04	0.2	1 tube at 2 650
SG3	< 0.04	< 1	1 000
SG4	< 0.04	< 1	860
SCO-I Limits [5]	0.4	4 000	4 000
SCO-II Limits [5]	40	8 × 10^4	8 × 10^4

The β, γ contamination of the SG2 was higher than the SCO-I transport criteria. All the SCO-II criteria were respected. For this SG, an application for transport under special arrangement was necessary, as discussed later in this paper.

Confinement

All the orifices of the steam generators were sealed by means of welded covers or plugs (Fig. 5 and 6). The welds were controlled by dye penetrant tests. These operations ensure the inaccessibility of the internal contamination, as imposed by regulation [5], to authorize unpackaged transport of SCO-I objects.



Cover plates	Name
S1	Steam secondary cover plate
S2	Water secondary cover plate
S3 / S6	Primary manhole cover plates
S4 / S5	Primary cover plates
S7 / S8	Hand hole cover plates
S9	Secondary manhole cover plate

Fig. 5. Localization of the sealed orifices: cover plates (S#) and plugs (#).

Fig. 6. Illustrations of the sealed orifices: cover plates and plugs.

Absence of Liquids

The presence of liquid is forbidden, both for SCO transportation and for acceptance in the VLLW repository.

The absence of decontamination solution in the primary part (water box and tube bundle) is justified by:

- An inclination of the SG after chemical decontamination
- A control performed inside the SG water box and the drying up of the internal surface of the waterbox and the lower tubes

In spite of this inspection, after decontamination of the SG4 and its exit from the controlled area, some residual activity was measured in two external zones (see Fig. 7).

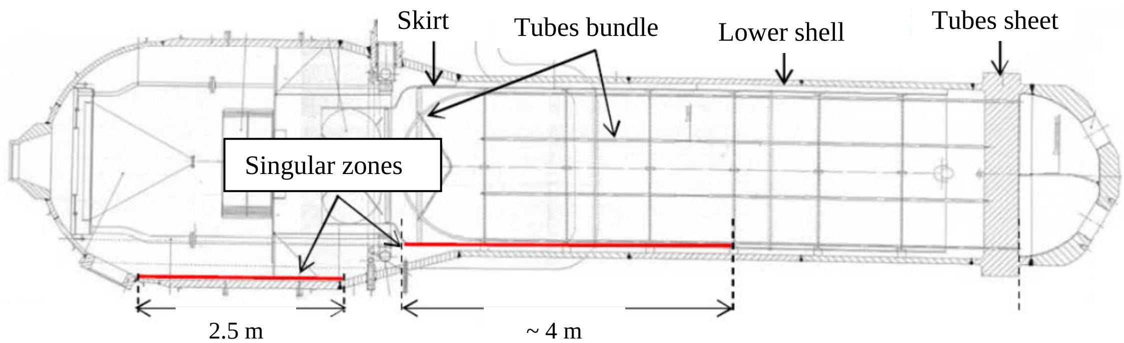


Fig. 7. Zones of the SG4 were residual activity was detected.

The hypothesis of the presence of an external contamination responsible for this residual activity was dismissed, as the use of a thin metallic cover in front of the gamma detector had no influence on the measurement. Similarly dismissed was the hypothesis of a serious leak between the primary and secondary circuits during the NPP operation as the contamination of the SG secondary system was not homogeneous.

Therefore it was concluded that a leak from one or more tubes of the primary part during decontamination had lead to the spreading of the decontamination solution into the secondary part of the SG (1). The solution may have flowed from the inside to the outside of the skirt (2), and then to the secondary steam part of the SG (3) during handling. This scenario is presented in Fig. 8. This SG had consequently to be reworked. The presence of approximately 30 dm^3 of decontamination solution was confirmed after inspection of the secondary part of the SG through the secondary manhole. The remaining solution was entirely removed and the SG wiped, after inclining the SG to ensure the total emptying of the skirt in the secondary steam part.

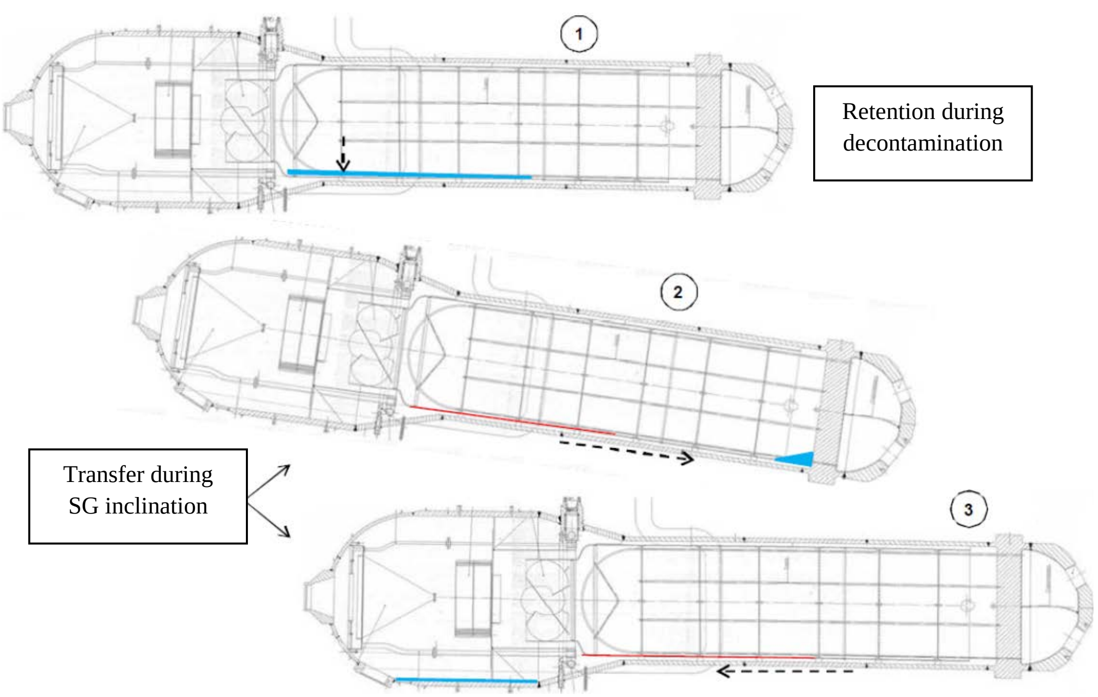


Fig. 8. Scenario of transfer of contamination supposed.

Absence of Fissile Matter

The mass of fissile material present in each SG is lower than 7 mg, the SGs are consequently fissile-excepted. The fissile radionuclides present are Pu239, Pu241 and U235.

Case of SG2: Transport under Special Arrangement

The analysis of the SG2 radiological characterization results have shown that all the SCO-I transport criteria were not respected after decontamination. The most contaminated part of the SG was the tubes bundle, for which the CORD© process was not 100% efficient, even though 1 655 unblocked tubes were efficiently decontaminated. Less than 1 m^2 of the 3 060 m^2 of inaccessible contaminated surface had a contamination level higher than the SCO-I transport criteria. The contamination levels on the accessible surfaces were much lower than the SCO-I criteria.

The SG was respecting the SCO-II contamination criteria, but SCO-II material should be transported in an IP-2 packaging, which is not possible given the SG dimensions and mass. The SG itself could not be considered as a packaging as it was not designed to resist IP-2 drop tests.

For these reasons EDF-CIDEN asked for an authorization of transport under special arrangement on the grounds that:

- SG2 was transported unpackaged
- No drop tests could be performed

A safety transport file was written for the French ASN to support the request. This file described the motive of the special arrangement and the reasons why alternative solutions were less favorable:

- Temporary storage at Chooz A waiting for SCO-I criteria achievement would last more than 20 years, which is contrary to the objective of the dismantling decree MAD-DEM
- Cutting of SG2 and use of adapted packaging would present security, radioprotection and fire risks
- Re-opening of the SG for reworking to reach the SCO-I criteria would present security and radioprotection risks

SG2 was the first of the four steam generators to be decontaminated and transported. Taking into account its feedback, the decontamination process of the three other steam generators was modified. Their tubes underwent chemical decontamination with cerium and the measurement methods were adapted to detect potential singular zones. The organization of these corrective actions allowed the three SGs to respect the SCO-I transport criteria.

To transport this SG under special arrangement in safe conditions, rigorous compensatory measures were applied during transport, as detailed below:

Transport and Stowage Conditions

The four SGs were transported between Chooz A NPP and ANDRA'S VLLW nuclear waste repository between 2012 and 2014. Three SGs were transported as unpackaged SCO-I, and SG2 was transported under a special arrangement. During the loading and unloading phases onto the trailer, no crane was used. The SGs were lifted by a jacking system with saddle extension.

Once on the trailer, the steam generators were supported by two cradles and anti-slip mats. These mats prevented lateral movement of the steam generators and reduced the acceleration forces by 60 %. During the dismantling operations, the four handling trunnions of the steam generators were removed, and replaced by four plates for the attachment of the retention system (see Fig. 9).

The steam generators were directly tied with twenty chains (20,000 daN each) attached to the plates (see Fig. 9). The retention system was designed according NF EN 12195-1 standard.

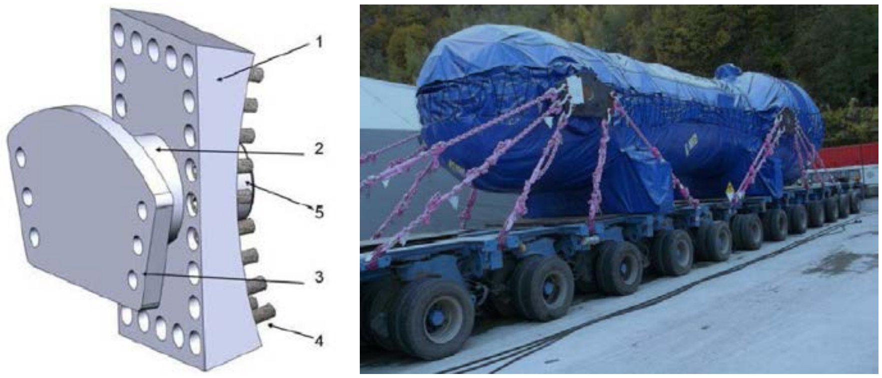


Fig. 9. System of plates used for the attachment of the chains.

The steam generators were shipped on a 14-line trailer (length: 20.4 meters), with one pull truck and one push truck. The overall length of the convoy was 45 m. Its overall weight was 230 metric tons.

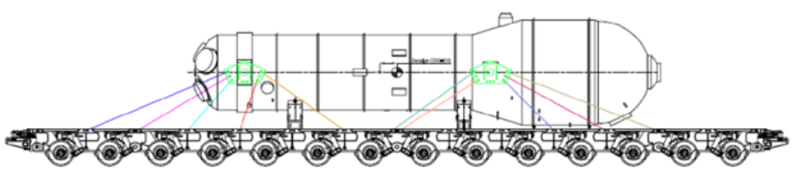


Fig. 10. Illustration of the 14-line trailer used.

The two first SGs left Chooz NPP on November 2012 and the two last ones on April 2014. The shipping took three days. The loading and unloading operations lasted one day each.

Fig. 11. One of the four SGs transported from Chooz A to the ANDRA VLLW repository, on a 14-line trailer with one pull truck and one push truck.

To ensure a safe transport of SG2 under special arrangement (and consequently of the three other SGs, as the same measures were applied), the following additional technical and operational measures were taken by EDF-ALN:

- A reconnaissance of the route was performed before transportation. All the obstacles were noted: the height of the bridges, their resistance, the width of the roads, and the parking spots for the night
- The weather report was consulted before transport. The transport was not allowed in case of fog or snow
- There was no loading / unloading during transport. It was exclusively road transport, with the same vehicle
- The speed allowed was reduced from 50 km/h (transport of heavy objects) to 40 km/h
- Road traffic was regulated by two motorcyclists
- The vehicle was permanently guarded throughout the transport including nights and days stops
- The retention system was checked before the shipment and after each stop
- The vehicle was followed by a maintenance truck
- Daily radiological controls were performed by the team during transport

CONCLUSIONS

The transport of the four PWR steam generators from Chooz A to the ANDRA VLLW repository was performed with success, in good security and safety conditions. The first experience of decontamination of SG2, transported under special arrangement, led to the organization of corrective actions which permitted the SCO-I transport criteria to be reached for the latter SGs.

In one case, the problem of a liquid presence had to be solved.

This example illustrates the difficulties induced by disposal and transport regulations, which are similar but with some differences, and show that transport rules are often more draconian. These constraints should consequently be integrated from the beginning of the dismantling studies.

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