QUALIFICATION OF STEAM GENERATORS FOR SHIPMENT WITH RESPECT TO THE REQUIREMENTS OF TS-R-1

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ABSTRACT

The paper presents the technical and organizational measures for the qualification of two steam generators for shipment under special arrangement from the nuclear power station KWO to the interim storage site of EWN GmbH in Greifswald, Germany by road and barge on inland waterways.

The first issue to be solved was the categorization of the steam generators with respect to the Regulations. Based on contamination and radioactivity SCO-II was the only possible classification with one uncertainty left. Due to the design of the inner surfaces which were not accessible it could not be proved that all inner parts of the steam generators comply with SCO-II.

Secondly, regarding their mass and geometry the steam generators could not be fitted into a packaging. For this reason they were qualified themselves to fulfill the requirements towards an industrial package of type IP-2 except of the position which leads to maximum damage during the drop test.

The third problem to be solved was to comply with the dose rate limits for conveyances. One of the steam generators has been equipped with an additional shielding to meet the admissible value in a distance of two meter from the road vehicle.

The last issue was the development of a tie-down system for the large parts to the heavy cargo trailers used for the road transport and for the barge. NCS devised a solution which provided adequate safety, reduced radiation exposure of the personnel and was economically favorable.

As the radiation protection for such big components is of particular importance a special radiation protection program was implemented for the shipment. All employees had been equipped with film badges to get an overview about the personal doses after shipment.

To comply with the requirements for quality assurance written instructions for handling and controlling during preparation, loading and unloading of the steam generators were set up.

INTRODUCTION

In 1983 two steam generators were dismounted in the nuclear power station Obrigheim (KWO), Germany and replaced by new ones. They were stored in an interim storage on-site for a limited period of time. The intention was to scrap the steam generators after the storage period. As no installation for scrapping such heavy components was available on-site and the interim storage was required for waste accruing from dismantling the reactor the steam generators had to be moved to the site of EWN GmbH in Greifswald, Germany. Fig. 1 and 2, which show the steam generators inside the interim storage, give an impression of the task at hand.

Figure 1. Interim storage of DE 1

Figure 2. Interim storage of DE 2

The paper will present an overview of the design, dimensions and mass of the steam generators as well as of the IP-2 proof and the additional shielding measures. Then the tie-down measures are shown. Explanations concerning radiation protection and quality assurance will conclude the paper.

DESIGN, DIMENSIONS AND MASS

The design of the steam generators is shown in Fig. 3. They consist of a thick shell of boiler plate which is closed at the bottom (primary) side with a spherical calotte and on the top (secondary) side with a dished end. At the primary side there are 3 welded nozzles with primary inlet/outlet and a manhole. At the top side there is the steam outlet in central position. At the cylindrical shell there are manholes and hand holes. Inside the steam generators there is the primary tube bundle attached to the tube bottom and secondary side installations. Main data of the steam generators are given in Table 1

Table 1. Main data of the steam generators

Characteristic	unit	
Total length	mm	16 580
Diameter	mm	3 600
Mass	kg	177 000

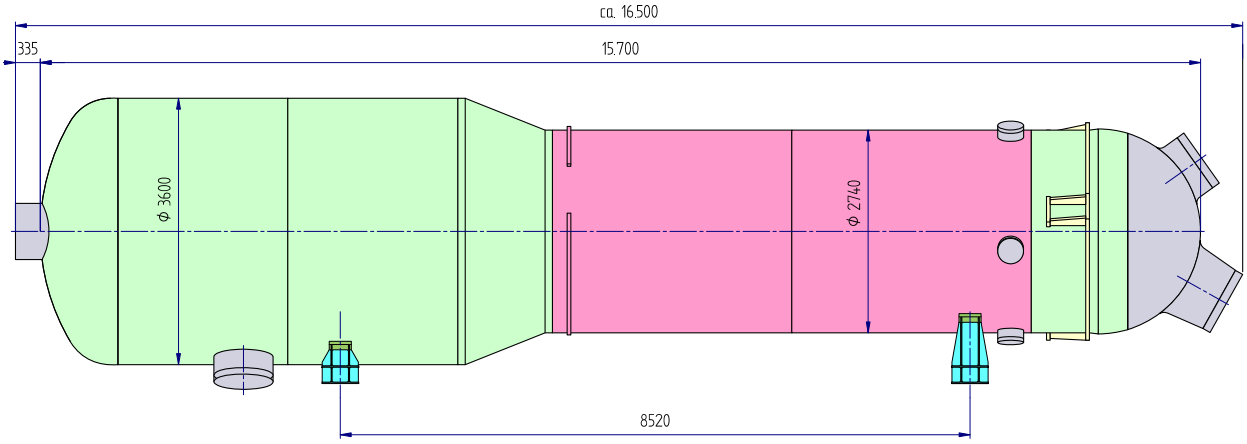

Figure 3. Outer dimensions of the steam generators

RADIOLOGICAL PROPERTIES OF THE STEAM GENERATORS

Contamination

For the categorization of the steam generators as SCO-II the fixed and non-fixed contamination of the accessible and inaccessible surfaces had to be assessed. The relevant limits are given in [1].

For the outer surface of the package the general contamination limits apply:

- beta and gamma emitters and low toxicity alpha emitters: 4 Bq/cm^2
- all other alpha emitters: 0,4 Bq/cm^2

First, samples of the contamination of the accessible surfaces taken during the decontamination of the steam generators some years ago were analyzed. The main radionuclides in the analysis were Co-60, Ni-63 and Fe-55 with a small amount of alpha contamination. Then, taking into account Co-60 contamination, dose rate calculations were carried out and compared with dose rate measurements on the steam generators. From the Co-60 contamination which resulted in comparable dose rates as measured and based on the composition of the samples the contamination contribution of other radionuclides was derived.

The average contamination derived with the procedure described above was less than 20% of the contamination limit for SCO-II. The same procedure applied to local hot spots near the manhole in the primary part of the steam generators resulted in contamination values which exceeded the limit by a factor of 2 - 4. This was the first reason for the special arrangement.

Radioactivity

The total activity of the contamination was derived from the above calculations and measurements. Conservative assumptions resulted in a total activity of less than 10 A_2.

Dose rate

Table 2 shows the dose rate limits for exclusive use shipments and the dose rates of the steam generators measured before shipment:

Table 2. Dose rates

	Limits	Measured values
surface of the package	10 mSv/h	0,695 mSv/h
surface of the vehicle	2 mSv/h	0,174 mSv/h
2 m distance from the surface of the road vehicle	0,1 mSv/h	0,047 mSv/h

IP-2 QUALIFICATION

According to TS-R-1 para. 622 a package to be qualified as IP-2 shall be designed to meet the requirements for IP-1 and, in addition, if it were subjected to the tests specified in paras 722 and 723, it would prevent:

(a) loss or dispersal of the radioactive contents; and
(b) more than a 20% increase in the maximum radiation level at any external surface of the package.

The general requirements for all packagings and packages as specified in TS-R-1 paras 606-616 were certainly fulfilled and the requirement of para. 634 (smallest dimension more than 10 cm) was obviously fulfilled as well. So the steam generators met the requirements for IP-1.

The stacking test as specified in TS-R-1 para. 723 was not applicable because the shape of the steam generators prevents stacking and stacking of objects of this size during transport was not a realistic or even feasible option.

What remained was the free drop test according to TS-R-1 para. 722 and according to TS-R-1 Tab. 13 the drop height had to be 0.3 m. The proof was carried out analytically by using Finite Element calculations with the 3D code LS-DYNA [2]. For the calculation model of the steam generators only the outer shell, bottom, head and the tube plate were considered. The primary inlet/outlet and the manhole in the primary chamber wall as well as the hand hole in the impact area were explicitly modeled. The total mass of the inner components and the mass of the additional shielding were considered, too.

The result of the calculations was that the global stresses in the shell of the steam generators were far below the yield strength of the material. Locally, at the primary inlet, the manhole and the hand hole there were large plastic strains. These strains were smaller than the breaking elongation but the competent authority required additional measures to increase safety. For this purpose two new transport cradles as shown in Fig. 4 were constructed. They were an integral part of the steam generators as IP-2 packages and prevented a damage of above components.

Figure 4. Transport cradle

It could thus be concluded that

- based on the negligible remaining deformations no increase of the maximum dose rate need to be assumed
- a release of radioactivity could be excluded because the integrity of the steam generators was preserved

With this it was proved that the steam generators fulfilled the requirements for a type IP-2 package but only in a drop orientation complying with the transport configuration and not so as to suffer maximum damage. This was the second reason for the special arrangement.

SHIELDING

For one of the steam generators the dose rates measured in two meter distance from the steam generator (equivalent to 2 m distance from the road vehicle) exceeded the limit of 0,1 mSv/h by a factor of four.
So it was necessary to design a shielding around the primary part of that steam generator to reduce the radiation level.

The shielding is shown in Fig. 5. It consisted of a 40 mm thick mild steel encapsulation comprising six independent parts which were mounted together by screws in axial direction. A special construction allowed installing the parts by crane as shown in Fig. 6. and reducing radiation exposure. Local shielding measures with lead reduced the dose rates at the hotspots at the bottom nozzles.

Figure 5. Shielding device

Figure 6. Assembling of shielding

TIE-DOWN MEASURES

A dedicated tie-down system was established to prevent any movement of the cargo during transport by road and barge. The challenge was to find a solution suitable for the spherical calottes at both ends of the steam generators, especially at the primary part. The basic acceleration values were taken from [3] and [4]. Fig. 7 and 8 show the tie-down equipment. During transport the steam generators rested on two supports mounted directly on the platform of the vehicle. Large supports, which were fixed to a base plate, prevented movements in axial directions. All connections of the different parts of the tie-down system were furnished with anti-sliding mats and were bolted to the heavy load road vehicle. These mats prevented lateral movement of the steam generators and reduced the acceleration forces by 60 %.

Figure 7. Tie-down secondary part

Figure 8. Tie down primary part

On the barge, the trailers were blocked in axial direction by wheel chocks welded to the bottom of the barge. Additional chains were used to prevent any movement of the vehicle on the barge. Fig. 9 shows one of the wheel chock devices.

Figure 9. Wheel chock on the barge

RADIATION PROTECTION PROGRAMME

With respect to the dose rate levels around the steam generators a special radiation protection programme was established. The main contents of this programme were instructions for measuring contamination and dose rate values and a detailed assessment of the expected doses for all persons involved in this shipment. It assured that the individual doses of the transport workers remain as low as reasonable achievable. Additionally individual monitoring was conducted to get some empirical values of the personal doses for shipments of such big components in the future.

Table 3 shows a comparison between the estimated doses and the doses monitored:

Table 3. Individual doses of persons involved

	Estimated values	Measured values
Road transport	1,52 mSv	0,08 mSv
Tie-down procedure	0,9 mSv	0 mSv
Barge transport	0,29 mSv	0 mSv
Transshipment	0,1 mSv	0,011 mSv

This comparison shows that the radiation protection implemented during this shipment ensured a high level of safety.

QUALITY ASSURANCE

A written process quality control plan for all phases of the shipment was established. All procedures for preparation, assembling of the shielding, loading of the road vehicle and the barge, tie-down and transshipment were fixe in detail. The execution of each step was confirmed by the responsible person by signature. This document assured a high level of quality during the whole shipment concerning all relevant requirements of the regulations [1].

CONCLUSIONS

The transport of large and heavy radioactive objects is almost challenging in the planning phase. The radiological properties of the object must be assessed in a conservative manner acceptable to the competent authority. For the design of shielding measures the radiation exposure of workers during installation has to be considered carefully. A leading point is the proof that such objects meet the requirements towards an IP-2 package with respect to the position during shipment. The tie-down is a more routine task as NCS has a long term experience in the transport of large and heavy objects up to a mass of 450 to. Possible radiation exposure of persons must be considered very carefully.

NCS is experienced in the transport of radioactive material and of heavy cargo. With its high qualified personnel and own equipment all steps of the planning and realization of such a transport can be carried out safely.

REFERENCES

[1] Regulations for the Safe Transport of Radioactive Material, 1996 Edition, No. TS-R-1, IAEA

[2] LS-DYNA, A Program for Nonlinear Dynamic Analysis of Structures in Three Dimensions, Version: 971s, Revision: 7600.398, Livermore Software Technology Corporation, 17.08.2006

[3] DIN EN 12195-1, Tie-down on road vehicles

[4] Guidelines for Packing of Cargo Transport Units (CTUs), IMO/ILO/UNECE