Steam Generator Safety Valve Replacement in Kola NPP

Nuclear power plant	Kola NPP
Project reference	R1.01/94C
Project name	Steam Generator Safety Valves Replacement in Unit 3 of Kola NPP
IAEA safety issue	S 09 qualification of SG SV for steam-water flow
Safety rank	II
Additional IAEA safety issue	S 10 Performance of SG SV at low pressures
Safety rank	I
Budget year	1994
Contract amount, Euro	1 604 749 Addendum - 3000
Contract status	Completed
EC endorsement of the contract	07.04.2000
Supplier	Sebim, (France)
Current status of the project	Completed, partial FAC signed 12.10.2005

1. Background: Safety significance of steam generator safety valves

The concept of defence in depth applied to all nuclear power plants (NPPs) relies on having four consecutive barriers preventing releases of fission products under normal and accident conditions and on various technical means to protect the plant and people by preventing and mitigating accidents and protecting the system of barriers. The barriers are

1. fuel matrix, which retains more then 99% of radioactive products created during and after fissions of uranium,
2. fuel element cladding, made of zirconium alloy, highly resistant to pressure and high temperature, which assures effective separation of fission products from the primary coolant,
3. pressure boundary of the primary reactor coolant system (RCS), designed with large safety margins to assure retention of such radioactivity which might penetrate from the fuel rods to the coolant. Pressure walls of the RCS are not only produced under the highest quality requirements but they are also regularly inspected to assure timely detection of any weak spots which might develop into more serious defects.
4. reactor containment, the fourth and final barrier enclosing all radioactivity in the reactor and assuring protection to the environment around the NPP.

In case of rupture of the reactor coolant system (RCS) piping and ensuing loss of coolant accident (LOCA) the primary coolant flows out of RCS but it remains kept within boundary of the containment, designed to withstand all loads and remain leaktight after LOCA. The coolant flashing out of the RCS flows down to the containment sump and can be recirculated through heat exchangers and into the core, to provide core flooding and heat removal from the core.

Thus the containment enclosing all RCS ensures that the water originally present in the reactor will remain available for core cooling after various accidents, even after LOCA. There is however one exception, and it gives importance to the issue of Steam Generator Safety Valves.

If the break in the RCS occurs in those pipes which are in the steam generator, for example in primary circuit header or in heat exchange pipes, then the primary coolant from the RCS will not flow to the compartments inside the containment, but will flow to the secondary side of the steam generator, and then along the piping of the secondary coolant system it will flow to the safety valves. It is called **Pri**mary to **Se**condary circuit leak or in abbreviation PRISE.

Since the primary pressure is much higher than the secondary coolant pressure, the safety valves will open and release primary coolant with some radioactivity to the environment. This radioactivity in the first phase of the accident is not high and its impact on human health is negligible. What is worse however, is the fact that at that time the coolant flowing through the valves will not be in the form of steam, for which the valves have been designed and tested, but in the form of steam-water mixture, or possible just water.

Since the valves are not qualified to operate with steam water mixtures, which provoke sharp pressure jumps and water hammer shocks, there is a hazard that the valves will be damaged and will remain in the open position even when the initial shock wave has passed and the pressure has been decreased below nominal opening point of the valves. If this is the case, then a severe breach in the system of barriers appears: instead of having a strong containment wall of a meter of reinforced concrete, the primary coolant encounters an opening in the secondary side system and flows freely out to the environment. This means not only a radiological hazard to the environment, but also irretrievable loss of cooling water from inside containment. Eventually, if the valves cannot be closed, there is the danger of losing more and mores water from the primary side, with eventually uncovering of the core, overheating of fuel elements and finally core damage or even core melting. Such an accident, with the primary circuit piping broken within steam generators as initially assumed and safety valves on the steam generator failing in the open position due to their inability to stand steam-water mixture flow, would result in an open pathway for the fission products from the core directly to the environment outside the NPP.

It is potentially the most severe accident in a NPP, because all barriers are lost – primary coolant boundary is assumed originally to have been broken in the steam generator, valves – which could be equivalent to the containment if they kept closed – fail in the open position due to their lack of qualification for steam-water flow, and the first two barriers, the fuel cladding and the fuel matrix also fail due to core overheating and melting.

This accident had been originally considered to be improbable due to robust design of steam generators, which prevents breaks of even single heat exchange pipes, while simultaneous breaks of several pipes are quite "beyond the design". However, as the events of very low probability and potentially large consequences are more and more addressed in the safety philosophy of nuclear power plants, the accident with large primary circuit breaks in the steam generator has been included in the range of those accidents for which design measures are taken. In addition, the experience of operation of NPPs with WWEWR 1000 reactors has shown that the cracks in primary circuit headers inside steam generators do occur.

In the late eighties and early 90-ies a series of such cracks were revealed, initiated by wrong technology of joining heat exchanger tube to the header and propagating during plant operation due to deviations form the prescribed water chemistry in the secondary cooling circuit. This was for some time an issue of high safety significance involving replacement of nearly twenty steam generators in WWER 1000 NPPs. Since then the technology of steam generator production has been changed and the water chemistry improved. Moreover, several safety measures have been introduced, aimed at fast decrease of primary pressure, before the whole water inventory from the core is lost. Together taken, these measures provide good basis for considering the issue as solved. Nevertheless, since the cracks have been really observed, the scenario of possible primary circuit break in the steam generator must be given the attention it deserves. The most reliable way to prevent coolant inventory losses through a failed open valve is to make sure that the valve can be always closed as needed.

The safety valves installed under TACIS programme are therefore qualified for steam-water flows, that means that the tests under accident conditions prove that these valves are capable of opening and closing reliably even when exposed to steam-water flow conditions. Even if a break occurs, the valves will be opened but then will close again, stopping outflow of water and thus ending radioactivity releases to the environment and preventing the hazard of core uncovery and damage.

Another requirement concerns valve ability to be remotely opened at any pressure, even a pressure much lower than the nominal opening point. What is the safety concern in this case?

Since the heat in the reactor is generated not only at the moment of fission itself, but also afterwards due to the radioactive decay of fission products, the core of the reactor must cooled even after reactor shutdown, although the amounts of heat to be removed are evidently much lower. This is why the reactors are provided with residual heat removal systems, provided with pumps which must be reliably supplied with electric power.

All NPPs are provided with electric power from the network, in most cases from two independent networks, and additionally from emergency power supply network with three or four diesel generators. Each of these diesels is sufficient to supply all needs of the NPP after shutdown, so there are three of four of them only for the purpose of assuring redundancy and providing high reliability of having power supply for NPP safety systems. These diesel generators are fully independent from one another, provided with separate control systems and fuel supplies, located in separated compartments etc. Therefore the case of total loss of electricity, from the external network, from the in-house power supply generated by the other units of the NPP and from all three independent and redundant diesel generators is highly improbable and treated as an accident beyond design basis of the plant.

However, the consequences of such an accident would be severe, because they would consist in loss of power to the cooling pumps and inability to remove the heat from the reactor, with the threat of reactor overheating and core damage. Therefore, even if a total loss of electric power at the site – called blackout – has a very low probability, it is still considered in safety analyses.

Even in case of blackout the heat from the core can be removed. This is possible owing to the natural circulation of water from the hot core to the cooler steam generator, where the heat of the primary coolant is transferred through the piping to the secondary coolant. The secondary coolant is heated up and evaporated, with steam being released through the safety valves of the steam generators. This provides several hours during which the heat is effectively removed from the core, at no cost other than the evaporation of secondary water.

In order to be able to remove steam from the secondary system the NPP needs safety valves on the steam generators that can be opened at pressures lower than the nominal working pressure of the secondary system and kept open even at very low pressures, until the water in the secondary circuit is fully evaporated – or until the electric power supply is restored.

In the rare cases of loss of electric power to the plant this strategy has been proved to be right. It is especially the case with WWER reactors, in which the inventory of water per unit power is larger than in western reactors, and thus offers possibilities of longer heat removal by water evaporation. In view of all precautions taken in the NPP design to assure reliable electric power supply even under accident conditions blackout is treated as a beyond design basis accident.

However, since under TACIS programme the contemporary safety philosophy of the European Union is transferred to for CIS countries, this accident is treated as a threat which must be prevented. The IAEA Issue books describe the problem of replacement of steam generator safety valves as the safety issue of rank II, that is high. Therefore the work on replacement of SG safety valves undertaken within TACIS programme involves deliveries of safety valves according to the leading EU technology, which ensures that the valves can cope with both accidents described above – they can work with steam water mixtures and ensure reliable closing after primary circuit break in the steam generator, and they can be remotely opened and closed at any pressure, which assures mitigation of blackout accidents. The project in Kola is only one of several such projects. Others have been implemented in the Russian Federation in Balakovo, Kalinin, Smolensk, Beloyarsk, Novovoronezh NPPs and in Ukraine NPPs of Rovno, and Zaporozhe.

2. Initial situation in Kola NPP

The originally installed steam generator pilot protective devices at Kola NPP, Units 3 and 4 (both with reactors of WWER-440/V-213 type), were based on 70's designs and formerly effective requirements and thus had the following safety deficits:

- They fail to meet the requirements of item 6.2.12 of the now effective normative and technical document PNAE G-7-008-89 where "*the use of pilot valves with lever-type drive is not allowed*";
- They have shown bad operational behaviour: There were recorded several failures (e.g. leakage, joint and rod steaming, false opening, failure to seat of pressurizer safety valve) and several times repairs had to be performed;
- They can operate on steam only, but for reliable heat removal from the primary circuit via steam generator under emergency conditions, they should be capable to operate also on steam-water mixture and water.

In order to improve the protection of the steam generators against over-pressurisation and to ensure reliable closure of their protection devices, it was decided to replace the original steam generator safety valves (SG SVs) by new ones. In total, twelve new safety valves, two for each steam generator, have been installed. These pilot operated safety valves have been manufactured by the French SEBIM group. Based on the equipment delivered by SEBIM these valves can only be operated in the pressure mode. For the solenoid pilot activation a special pilot protective device control unit is needed, the unit BUP-35P. It allows also remote controlled safety valve activation from the control rooms at any pressure, including low pressures. This makes is possible to use the valves for controlled release of water steam mixture from the secondary cooling circuit in case of a severe accident with total loss of electric power to the NPP so called "blackout" accident.

3. Course of implementation

The project was proposed under 1994 budget and accepted. The call for tender was made in November 1997, and on 27 October 1998 SEBIM was selected as the supplier. However, due to the two years break in OSA consultancy at the site the contract with SEBIM was endorsed by the EC only in March 2000.

Since the project concerned items of high importance to safety, classified as Safety Class 2 they were subject to licensing by Russian safety authority, supported in this process by Riskaudit. This support was provided by the European Commission under so called 2+2 approach, where on each side of the licensing discussions there were two partners: on one side the NPP and a EU utility being its On –Site Assistant, on the other hand Russian Safety Authority and its Technical Support Organisation (TSO) supported by Riskaudit as the EU TSO cooperating with safety authorities in former CIS countries under TACIS programme.

The licensing of safety valve replacement in Kola NPP was made in the frame of TACIS project RF/TS/31. Under this project, the licensing process is divided into ten steps, and the licensing analyses for the safety valves covered the first five stages up to Preliminary Safety Analysis Report, Technical Specification and engineering documentation for manufacturing provided by the supplier, and the last two stages - post modernization (commissioning) tests and license amendments for the NPP.

In the course of joint work of Western and Eastern experts several aspects of documentation were discussed and improved, the programme of testing approved and additional required calculations specified. One comment was related to the layout of the system and resulted in its change, because the licensing analysis showed that both pilot protective valves of each steam generator were supplied with power from a single channel of the emergency power supply system. This was a violation of single failure principle. In response to this remark the power to two valves of a single steam generator was provided from different channels of the emergency power supply system.

After the review, the experts of RF TSO and of Riskaudit recommended to RF Gosatomnadzor to issue the licence for permanent operation after some minor modification demands have been satisfied.

The project has been completed as per schedule. The factory tests took place on 15 June 2000, so only 3 months after signing of the contract and delivery was completed in December 2000. The installation in Units 4 and 3 was performed in April and September 2001 respectively and the preliminary acceptance certificates (PAC) were signed in April and November 2001. Two small defects were revealed in Unit 3 and initially were planned to be repaired during the 2002 summer outage, but then in the process of elimination of a defect of the valve it was decided to replace the valve body. The new valve body was delivered to Kola NPP in January 2004.

The warranty period on this valve was prolonged until August 2004. FAC (partial) was signed 12 10.2005, without covering the valve ref. 1836S, because that valve was repaired during the warranty period.

The staff of SEBIM cooperated well with the plant and the certification problems were resolved quickly and efficiently. It is the only specific project (with equipment supply) in Kola NPP that was completed within the contract period.

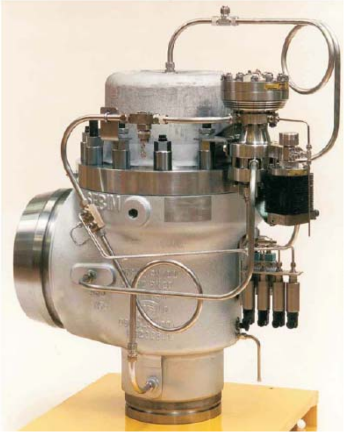
4. Sustainability of the project

In parallel with Kola NPP also Balakovo, Kalinin and Smolensk NPPs started similar projects and in Ukraine they were started in Rovno unit 3 with WWER 1000 in December 1999, in Rovno units with WWER 440/213 reactors in February 2000 and in six WWER 1000 units in Zaporozhe in September 2004. The course of implementation is good, with the valves in Armenia, Balakovo and Rovno having already FACs, and the other valves already delivered except for Zaporozhe NPP.

High acceptance of the project and of SEBIM valves is the fact that NAEK has already ordered SEBIM valves at its own cost for Rovno 4 and Khmelnitsky 2 NPPs. Moreover, there are discussions going on about equipping South Ukraine NPP with Sebim valves.

This project shows the best features of TACIS OSA undertakings: Its aim is to upgrade nuclear safety, both under normal or transient conditions and under accident conditions up to severe accidents, it is fully accepted by the Beneficiaries and the plants as needed, it introduced technological achievements of EU industry for use in nuclear safety upgrading in RF/U/A NPPs, was implemented efficiently and timely and provided a good opportunity for meaningful cooperation of safety experts from RF and EU, thus helping in the process of gradual harmonisation of nuclear safety regulations and approaches.

A photo of a steam generator safety valve of SEBIM company installed within TACIS project in Balakovo NPP is shown above. In that project the contract was signed on 14 December 1999, Factory tests were made in September 2000, delivery followed in November 2001. However, the plant was not ready to install the valves during the shutdown period on 2002 and they had to wait till the plant maintenance period in 2003. In July 2003 the PAC and in July 2005 FAC was signed.



Steam generator safety valve of SEBIM company installed within TACIS project in Rovno Unit 1

In that project the contract was signed on 23 March 2000, Factory tests were made in February 2001, delivery followed in March 2001, provisional acceptance was given in June 2001 and after the test period final acceptance was signed in December 2002.

The speed of implementation of the project was very good.

Problems with maintenance

Although the SEBIM valves have many undoubted safety advantages, their maintenance involves significant costs, and various technical problems. For example in Kola NPP, where these valves were installed nearly a decade ago, the actual maintenance issues include:

a) Different technical problems revealed during the operation of the safety valves, e.g.: cracks on the valve bodies, leakages of the bellows seals and glands, some components are made from carbon steel (whereas austenitic steel stated in the documentation), controllers defects and failures, shaft jam, etc.

b) Planned maintenance to be performed once in ten years is costly. In the manufacturer documentation there is a parts' list subject to replacement (mandatory) after ten years of operation. According to official representative SEBIM in Russia (WVCF) in 2006 cost of those parts per Unit would be ≈ 1 mln Euro *(to compare the price of the whole contract for both Units in Kola NPP was 1.5 mln Euro)*

c) Personnel training insufficient to perform maintenance of some parts. Additional more detailed training would be desirable.

Thus the decision to install EU equipment should be always taken with consideration of later problems, in particular maintenance costs, which can be significant.

Safety advantages achieved

- Replacement of the obsolete Safety Valves by updated equipment
- Reliable operation of the Safety Valves with two-phase mixtures
- Monitoring of the position of the main and pilot valves
- Easy maintenance of the Safety Valves
- Remote control at low pressure
- Adjustment of the closing pressure of the Safety Valves
- No leaking to the environment during valve operation.

In summary, IAEA safety issues connected with potentially possible leaks from primary to secondary circuit and blackout hazard have been resolved.