STEAM GENERATOR LEAKAGE AT THE BN-350 DESALINATION PLANT

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INTRODUCTION

The BN-350 sodium cooled fast reactor was constructed near the city of Aktau, formerly Shevchenko on the Caspian Sea in Kazakhstan, and was placed in operation in 1972.

BN-350 was designed as a dual purpose plant of producing 130 MWe of electricity and 150 MWth for desalting water and the production of 120,000 m^3 of fresh water/day, which corresponds to a total power generation of 750 MWth.

The system was built as a pilot plan to prove that a commercial size fast reactor could be constructed for electricity and fresh water production. Experience has shown that the operation and maintenance costs in terms of reliability, availability, and capacity factor of power generation for the BN-350 plant were economically competitive with traditional fossil fuel or light water reactor power plants. However, the capital cost was high for this demonstration plant. The BN-350 reactor system has also been utilized for a wide range of experimental work supporting fast reactor development; and several design improvements were developed for the next generation larger power sodium cooled fast reactor BN-600 plant.

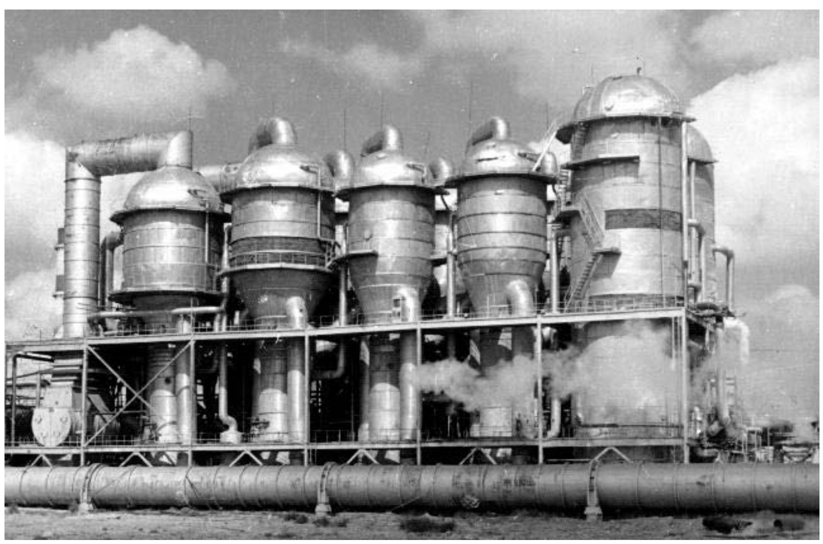

Figure 1. Desalination units at the BN-350 plant.

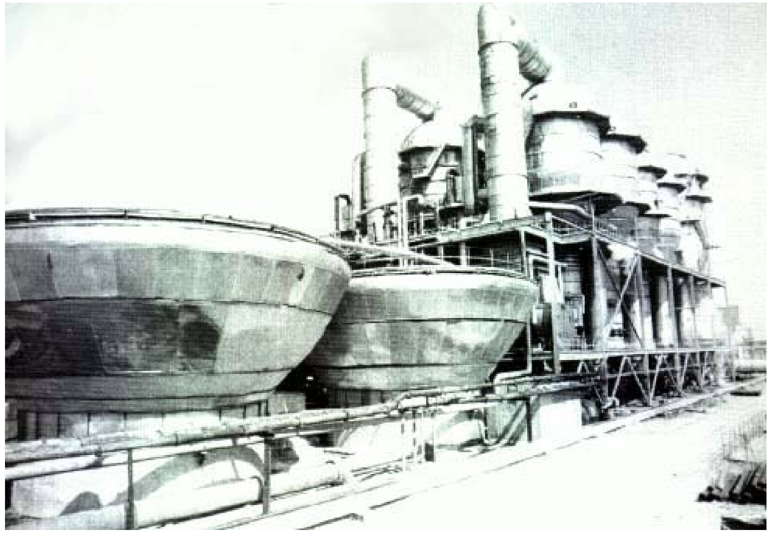

Figure 2. BN-350 sodium cooled fast reactor for desalination at Aktau, formerly Chevchenko, on the Caspian Sea.

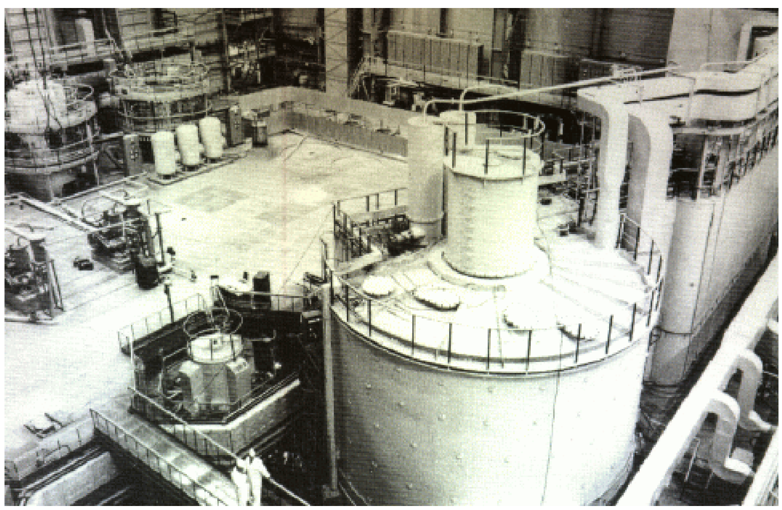

Figure 3. Reactor hall of the BN-350 plant.

TECHNICAL SPECIFICATIONS

The 750 MWth BN-350power station was located on the eastern shore of the Caspian Sea, 2 miles inland, near Akatau, formerly Shevchenko in Kazakhstan. It was a dual purpose plant producing 130 MWe of electrical power as well as 150 MWth of power for desalination and fresh water production.

The reactor went critical in 1972, achieved partial power in 1973, and was shutdown in 1994 after 21 years of operation. During early operation over the period 1973-1975, the power level was limited to 350-550 MWth due to leaks in steam generator evaporator tubes.

The plant was designed for 5 out of 6 desalination loops in operation, with one loop left as a spare for maintenance. In each loop, two evaporators with bayonet tubes were used, as well as two superheaters with U-tubes.

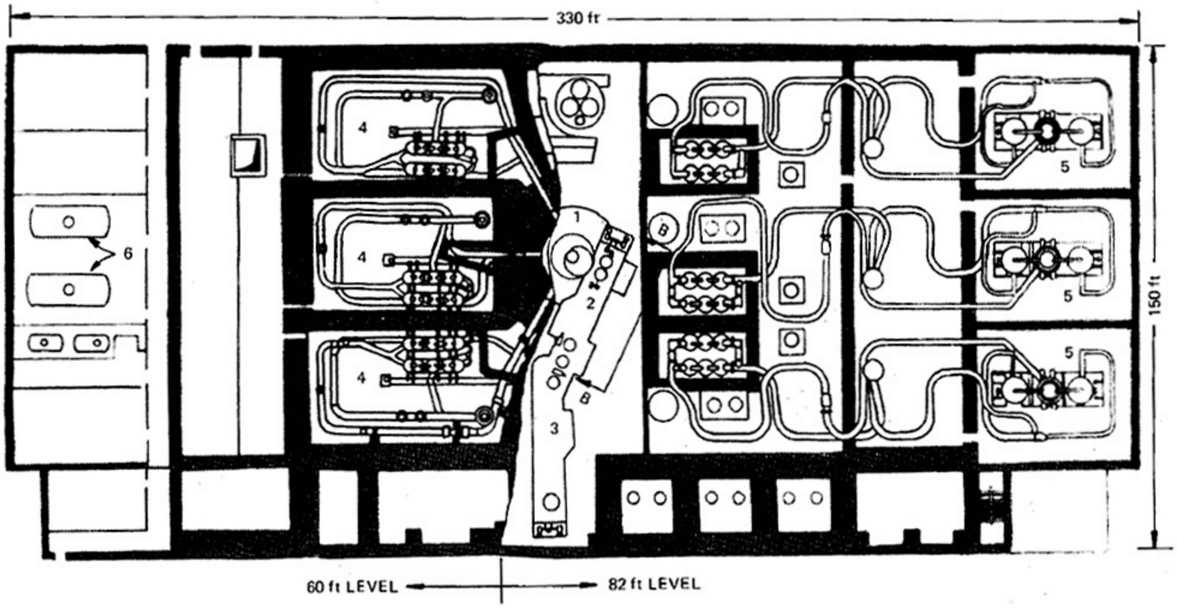

Figure 4. Plan view of the BN-350 desalination reactor building. Symmetrical layout showing three loops to the right of the reactor and 3 to the left. 1: Reactor, 2: Refueling cell, 3: Wash well, 4: Three of 6 Intermediate Heat Exchangers, IHX compartments, 2 shells in each compartment, 5: Three of 6 steam generator compartments, 6: Secondary dump tanks.

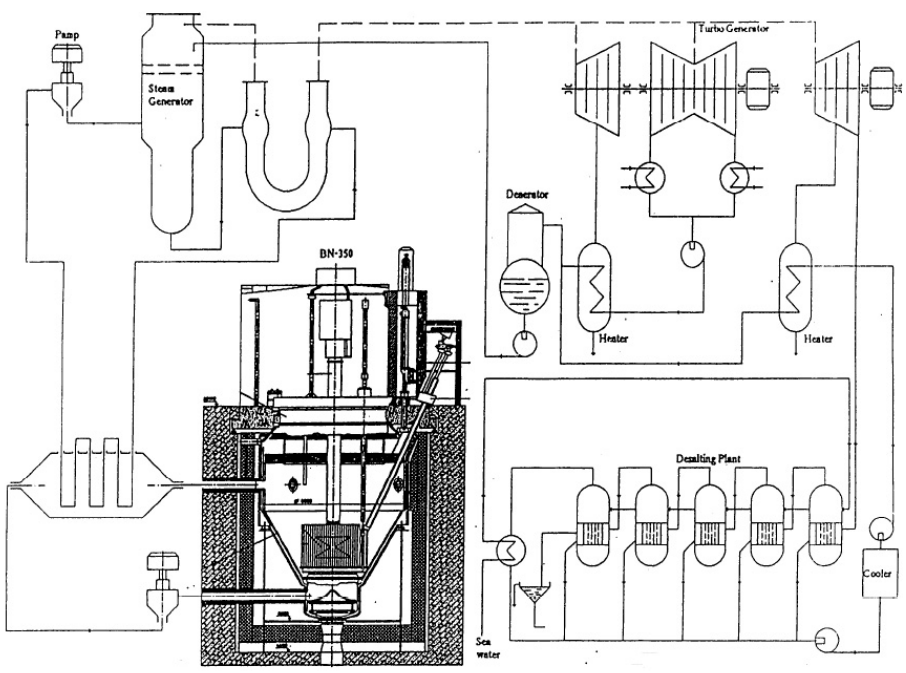

Figure 5. Nuclear desalination complex at the BN-350 plant.

Each evaporator contained 816 bayonet tubes that were 3.3 cm in outer diameter and 3 mm in thickness with a welded end cap and a 1.6 cm x 1.4 mm internal downcomer tube. These were a modification of an earlier design that was 3.2 cm x 2 mm in dimensions.

During the startup tests, leaks were detected at the tube sheets welds and the end cap welds. In operation, eight evaporator leaks occurred through 1975 involving all but loop 4 of the loops.

Even though loop 4 never experienced any leak, three major leaks lead to extensive damage.

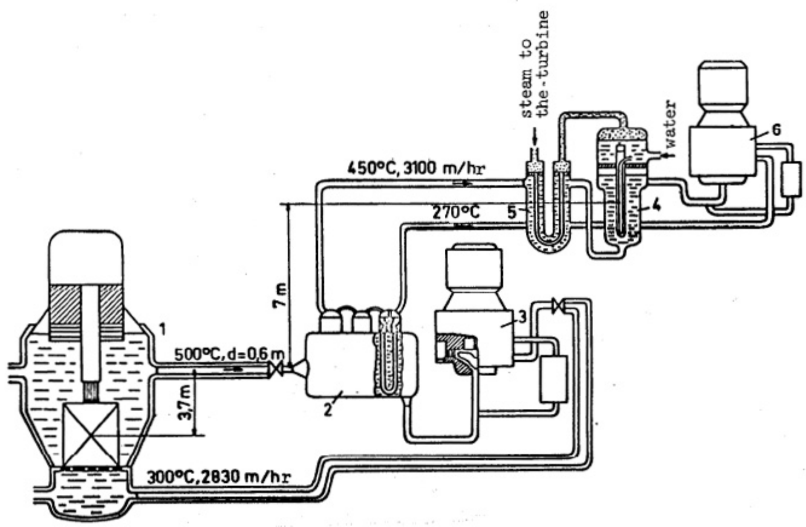

Figure 6. Single cooling loop in the BN-350 plant. 1: Reactor, 2: Heat Exchanger, 3: Primary coolant pump, 4: Steam generator, 5: Steam superheater, 6: Secondary cooling pump.

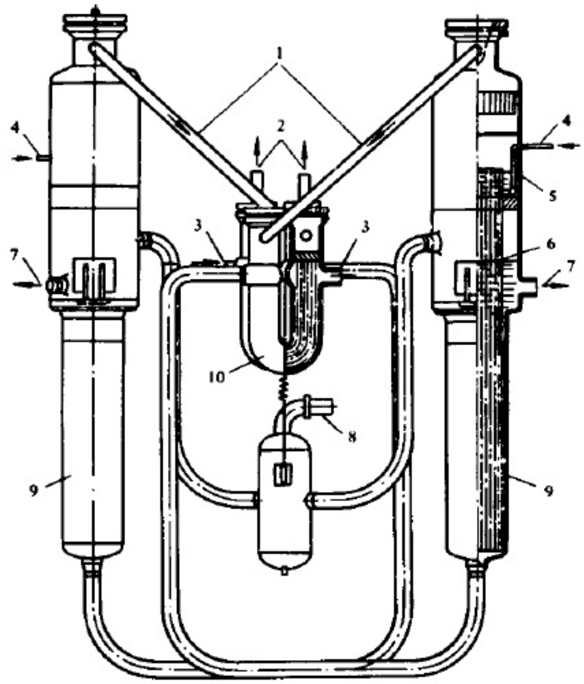

Figure 7. BN-350 steam generator. 1: saturated steam inlets, 2: Superheated steam, 3: Sodium inlet, 4: Feedwater inlet, 5: Water level, 6: Sodium level, 7: Sodium outlet, 8: Burst diaphragm, 9: Evaporator, 10: Superheater.

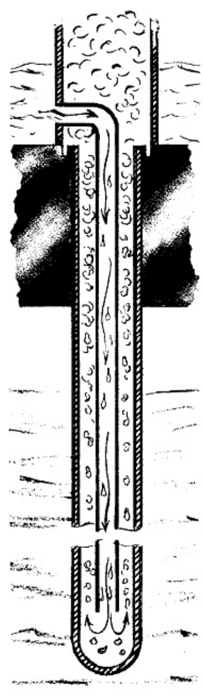

Figure 8: BN-350 bayonet steam generator.

STEAM GENERATOR LEAKS AT BN-350

Through 1974, two major leaks and three smaller leaks occurred at the BN-350 plant. They were initiated from the end cap welds and caused by micro cracks in the end cap weld seam zone. They were attributed to mechanical deformations introduced during the end cap manufacture process.

In 1974, a decision was taken to replace the tubes in all the evaporators except loop number 4 which did not experience any leaks.

After 7 days of operation, one of the evaporators in the recently re-tubed loop number 5 failed leading to a significant leak. In that event 120 tubes failed with 800 kg of water leaking, possibly interacting with the sodium causing a fire.

This steam generator was dismantled and was replaced by steam generator manufactured in Czechoslovakia.

It was reported that the safety systems including the rupture disc and the blowdown system prevented the destruction of the evaporator vessels for the three large leaks, resulting in no sodium leaks. It is thought that the reaction products stayed within the vessel shell, aggravating the tube failure propagation.

After the re-tubing process, some leaks continued to occur. However emphasis on sodium and feedwater quality control, early leak detection and remediation through failed tubes plugging, eventually resulted in a stable plant operating at design power levels.

LESSONS LEARNED

The problems with leakage in the steam generators at the BN-350 plant posed a problem because of the possible interaction of water with the sodium coolant. The leaks were reportedly confined to water leaking into the sodium. No sodium leaks were reported, which itself would react with oxygen in the air, also causing a fire.

Improved steam generator component manufacturing techniques were developed, particularly in tube drawing, forging and welding.

This suggests a need for designing such systems for failure prevention, sodium and feedwater quality control.

This suggested the need for including design provisions for tube failure detection with quick recognition and action to prevent failure propagation, and methods for the remediation and plugging of mleaking tubes.

Design provisions should also be included for containment and blow-down relief to control the intermediate sodium system pressure.

DISCUSSION

In June 1994, the BN-350 reactor was shut down because of a lack of funds to buy fuel after the separation of Kazakhstan from the Soviet Union. In addition, the operating license of BN-350 had expired. It was reported that Russia's Ministry of Atomic Energy (MINATOM) proposed a joint project to the Kazakhstan Atomic Energy Agency for extending operation of the BN-350 by up to 10 years, then decommissioning it and providing replacement power. The Kazakhstan State Corporation for Atomic Energy instead planned to build a new 135 MWe fast reactor to replace the BN-350.

The BN-350 reactor plant is an outdated loop design, where the reactor is located in a separate vessel, and piping connects the reactor vessel with all other major system components, such as coolant pumps, and the intermediate heat exchangers. At some point it suffered a sodium water fire accident. Modern designs of fast reactors favor the pool design rather than the loop design, offering enhanced safety features, so it is doubtful that it will be brought back on line, and it should be decommissioned.