Retrofit for 20 years old reactor in the Oskarshamn 1 nuclear power plant

For the first time in the history of nuclear energy, workers have carried out repairs on the bottom head of a reactor pressure vessel which has been in operation for more than 20 years. Working within the framework of the OKG FENIX project, the goal of which is to extend the power generation capability of the existing plant, ABB Atom carried out extensive inspections and repair work inside the pressure vessel of the Oskarshamn 1 nuclear power plant. The retrofitted components now comply with the Swedish nuclear inspectorate's conditions for renewal of the plant's operating licence. It is planned to further modernize the power plant in a second project phase that will last until the year 2000.

The reluctance of most countries to grant licences to build new nuclear power stations has led the nuclear energy industry to see reconditioning and retrofitting of their plants as key options in their operations planning. Nuclear power station operators have a special interest in keeping their plants fully functional and in carrying out modernizations when necessary, in order to maintain their reliability and ensure a high energy yield. Upholding the value of the original capital investment is another priority of the utilities.

Design philosophy at ABB Atom

During the development of its boiling-water reactors, ABB Atom already committed to designs that would ensure good accessibility for inspections, maintenance work and repairs. This included bolting or clamping the core internals (ie the parts inside the reactor pressure vessel) together, rather than weld them, as is the practice of other reactor vendors. In other words, the realistic option of carrying out repairs to or replacing such parts, which are normally inaccessible, has been designed into the reactor by ABB Atom from the start.

Routine maintenance and overhauling of nuclear power plants

Nuclear power plants are shut down once a year for the annual refuel and for routine maintenance and overhaul work. Inspections concentrate mainly on individual component wear. Any signs of damage which could restrict operation of the plant has to be detected and corrected in good time if the plant is to continue running with the same high availability and operational reliability. The incremental replacement of specific components allows operators to keep their plants state of the art.

Niclas Säll
Tore Waltersten
ABB Atom

Oskarshamn 1 – Sweden's oldest nuclear power plant

Oskarshamn 1 was the first nuclear power plant to be placed in commercial operation in Scandinavia **1**. The operator, OKG, a consortium made up of private and communal power supply companies, awarded the contract for the turnkey plant in 1965. ABB Atom was chosen as the main supplier. The guaranteed net electrical output of the boiling-water reactor is 400 MW, but this figure could be raised to 440 MW by the time the BWR was delivered. Work on Oskarshamn 1 began in 1965, and the plant went into commercial service at the beginning of 1972.

Inspection of the reactor

The reactor of the Oskarshamn 1 nuclear power plant as well as four other Swedish reactors with external reactor coolant pumps were shut down in September 1992. It was feared by the nuclear authorities that in the event of a tube fracture inside the containment, parts of the tube insulation could peel off and block the screens in the pressure suppression pool in front of the inlet opening of the emergency core cooling system.

The management of Oskarshamn 1 decided in favour of a detailed inspection of the reactor's technical state. This inspection showed, among other things, surface cracks on the cold-worked elbows of the tubes and piping in the containment. Further inspection with the help of TV cameras detected continuous cracks in four of the six feedwater tubes in the reactor pressure vessel close to the RPV penetration.

The result of these inspections was that the Swedish nuclear inspectorate made a comprehensive overhaul of the nuclear plant a precondition for its continued longterm operation. The operator subsequently initiated an extensive retrofit project for the purpose of meeting the conditions.

The project, which goes under the name FENIX[1], is being carried out in two stages. The first phase, for repairs, has been concluded and the reactor could be restarted again in January (1996). The second phase, during which the nuclear plant will be modernized to further improve reliability and availability, will last until the year 2000.

OKG contracted ABB Atom in the summer of 1993 to submit proposals for the preparation of the reactor pressure vessel of Oskarshamn 1 for a thorough inspection and subsequent repairs **2**. At a later date, ABB Atom was also contracted to supervise and carry out the work. This was preceded by the development of the special equipment and tools that would be needed.

Oskarshamn nuclear power plant on the Baltic Sea coast. Oskarshamn 1, Sweden's first commercial nuclear facility, is on the left. The plant, from ABB Atom, began operating in 1972 and today exhibits a net electrical output of 440 MW. **1**

Clean-up of the reactor pressure vessel

In order to closely inspect the bottom head of the pressure vessel, including the nozzles, the fitters had to work on the bottom of the vessel. First of all, it had to be clarified whether the idea of letting people work inside the pressure vessel was viable at all, ie, whether the radiation exposure could be lowered to a safe level. ABB Atom's initial task was therefore to calculate the radiation field level that could be expected in the pressure vessel.

Firstly, all of the fuel elements and core internals had to be dismantled, lifted out of the pressure vessel and placed in the storage pool in the reactor hall.

A special problem in the Oskarshamn 1 plant was that there was no partitioning wall between the reactor well and the storage pool for the core internals. To overcome the problem of how to empty the reactor pressure vessel and at the same time ensure that the core internals remained under water in the storage pool, ABB Atom designed a special large steel cylinder for mounting on top of the RPV. After all the core internals had been dismantled, the steel cylinder was lowered into the storage pool and mounted on the flange of the pressure vessel. The steel cylinder was dimensioned so that its top edge was level with the floor of the reactor hall **3**, allowing inspections and work in the reactor pressure vessel to be carried out in a dry environment. This solution enabled the inside wall of the lower part of the pressure vessel, the coolant recirculation loops and the residual heat removal system to be thoroughly cleaned and decontaminated.

Radiation shielding

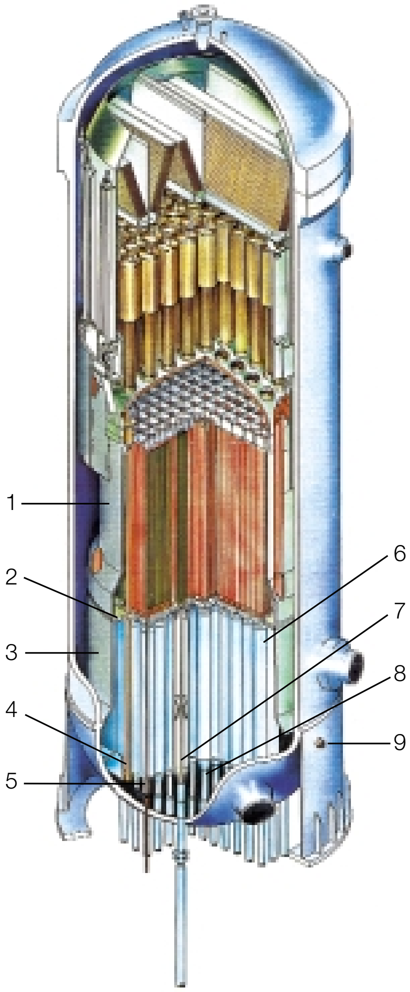
After removal of all of the equipment and decontamination of the lower part of the reactor pressure vessel, a radiation shield was mounted on the inside wall of the reactor. This shield, in a three-part telescopic arrangement, incorporated an elevator for transporting the technicians to and from their workplaces in the reactor pressure vessel **4**.

The design of the shield was based on the radiation field levels calculated by ABB Atom. Because of the high dose rate on the pressure vessel wall in the area of the reactor core, the shield had to be 100 mm thick at this point. The lower section of the shield was fitted with movable platforms to provide the workers with easy access to the wall of the RPV and the feedwater system penetrations through the vessel. Openings were also provided in the floor through which the bottom nozzles of the vessel could be reached. In this way, conditions were achieved on the bottom of the reactor pressure vessel by February, 1994, which were comfortable as well as safe.

Radiation was reduced by 99.88 percent

After decontamination (CORD), high-pressure flushing and erection of the radi-

[1] FENIX, Swedish for 'phoenix', a symbol chosen to represent the goal of extending the power generation capability of existing plants.

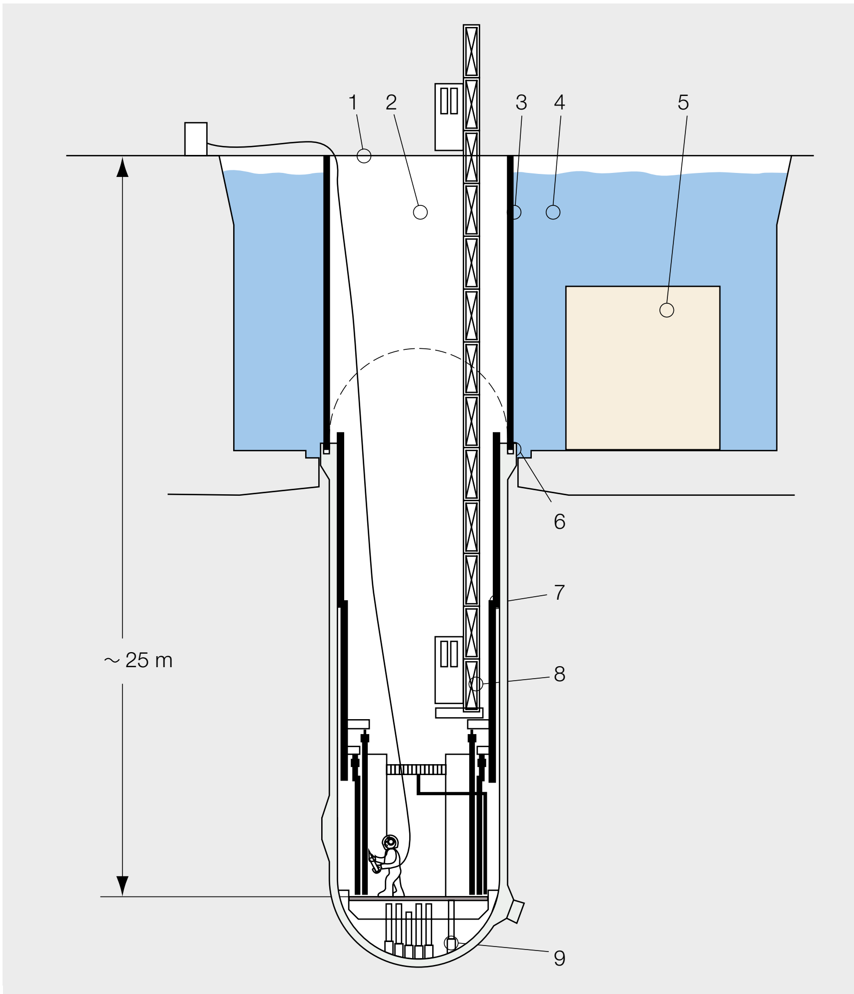


Section through the reactor pressure vessel in the Oskarshamn 1 nuclear power plant. The locations involved in the FENIX corrective maintenance project are indicated. **2**

1 *Core shroud repairs*
2 *Replacement of bolted connections between core shroud and shroud support*
3 *Replacement of core shroud support*
4 *Replacement of piping of reactor water level controller and fitting of 2 additional pipes*
5 *Sealing of obsolete instrument nozzles*
6 *Replacement of tube for measuring pressure drop across core*
7 *Repair of neutron detector housings*
8 *Replacement of tubes, nozzles and nonreturn valves in emergency core cooling system*
9 *Replacement of feedwater piping and nozzles in pressure vessel up to top part of core shroud support*

Simplified diagram of the reactor pressure vessel with the steel cylinder and radiation shield with elevator that were installed for the repair work **3**

1 *Floor level of reactor hall*
2 *Access to reactor pressure vessel*
3 *Steel cylinder*
4 *Storage pit for core internals (separated from 2)*
5 *Core internals*
6 *Flange of reactor pressure vessel*
7 *Three-part telescopic radiation shield*
8 *Elevator*
9 *Bottom head supports*



ation shield, the radiation in the bottom section of the reactor pressure vessel was 99.88 percent lower than before. On the floor of the pressure vessel, the decontamination factor was even better than 1,000, the dose rate having fallen from 20 to less than 0.02 mSv/h. This allowed unrestricted work in a risk-free environment. Protective clothing was nevertheless worn by the technicians working in the pressure vessel as an extra safety measure.

Non-destructive testing

The weld seams in the lower section of the reactor pressure vessel and on the pressure nozzles were carefully inspected before repair work began. Special attention was paid to the bottom head and its nozzles. Only after completion of this inspection did the utility make the final decision to proceed with the reactor repairs.

Corrective maintenance of the reactor

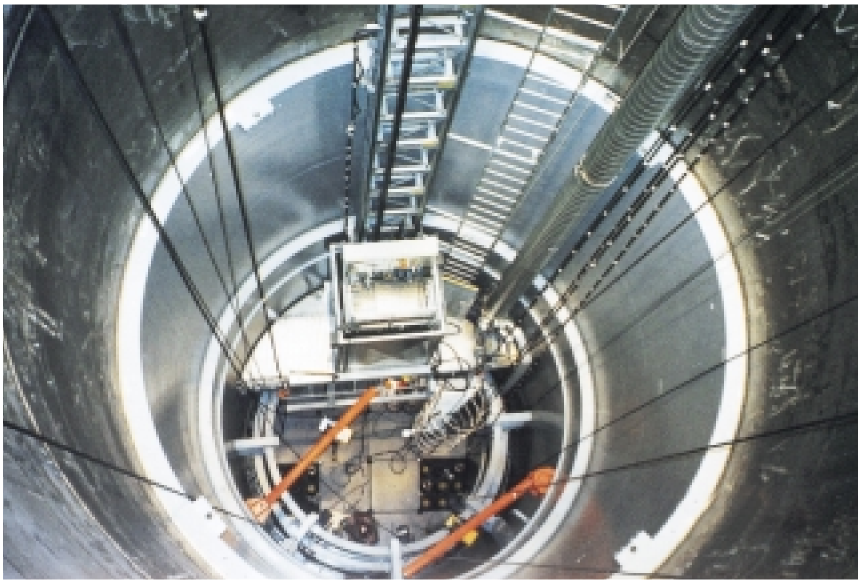
In April 1994 ABB Atom was contracted to submit a programme for carrying out corrective maintenance on the reactor and the pressure nozzles that would ensure compliance with the stipulations of the nuclear authorities. ABB Atom was also entrusted to carry out the majority of the repair work.

The order called for, among other things, the replacement of six feedwater risers, including the penetrations, inside the pressure vessel **5**, the penetrations for the core spray system and all the piping used for level measurement. Other work included repairs to the housing for the neutron detector and replacement of the core shroud support. Finally, the reactor pressure vessel and the core internals had to be made ready for operation again.

Design and procedural improvements

To reduce the number of weld seams to be tested, ABB Atom introduced design improvements at various locations. For example, the pressure vessel wall penetrations for the feedwater tubes, which had been welded in the past, were replaced by forged parts.

A special challenge was the replacement of the core shroud support, which was necessary on account of surface cracks that had been found in the flange. A large, transportable vertical milling machine, installed on the bottom head of the pressure vessel **6**, was used to separate the old shroud. The new welding joints were machined with very high accuracy, for example with a maximum discrepancy of ±0.2 mm for an internal diameter of about 5000 mm. A full-scale mock-up was built as part of the approval procedure for the fully automatic welding process and for training purposes.

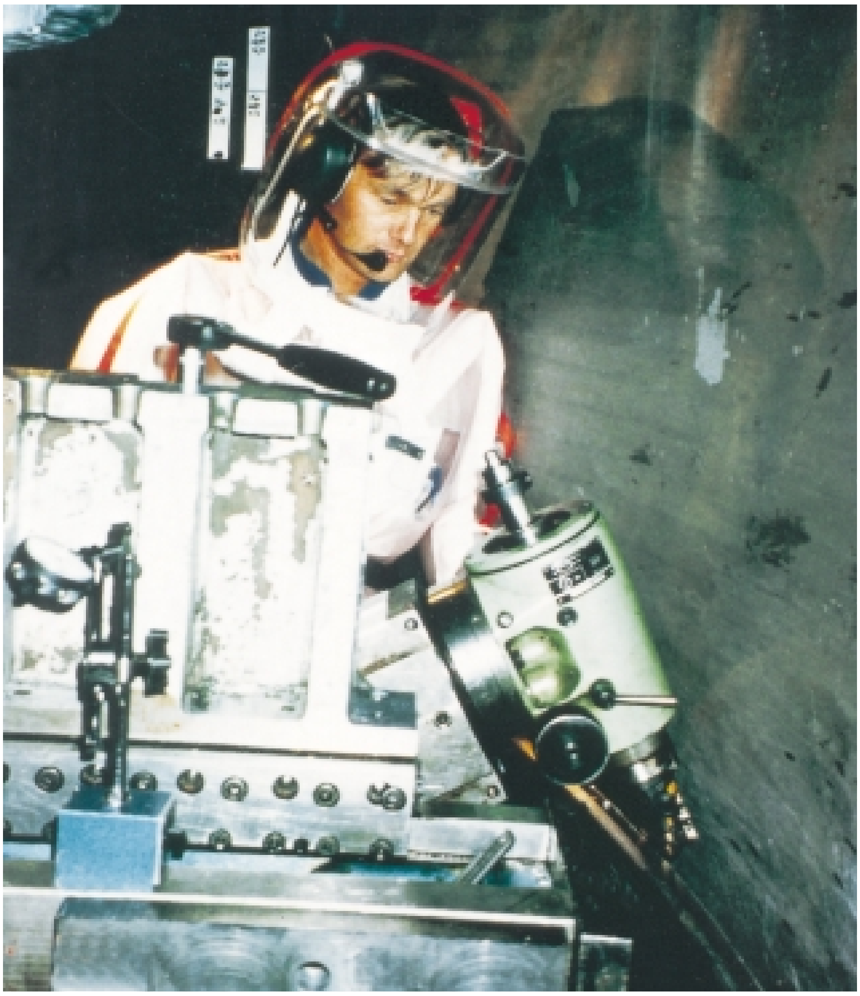


Steel cylinder and radiation shield with elevator in the reactor pressure vessel **4**

Analysis of the latest materials know-how

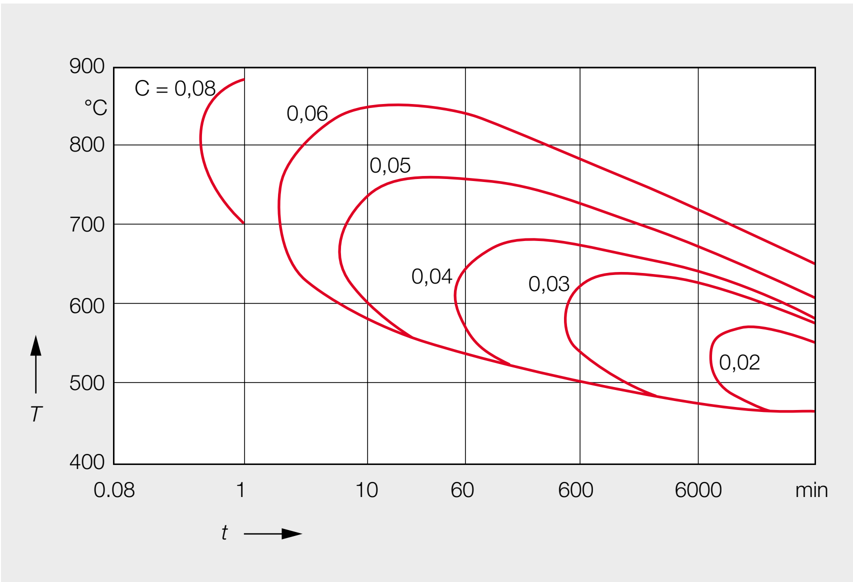
Since delivering its first reactor, ABB Atom, has built up a comprehensive database with information on the properties of the different materials used in the nuclear sector. It is based on the results of its own research projects as well as those of projects funded by the power industry in general. The projects include studies carried out by ABB in its own materials laboratory. Samples of materials from several reactors in commercial operation have been analyzed in order to research the effect of the primary loop water chemistry on the materials.

Welding feedwater pipes in the reactor pressure vessel **5**



Separating the core shroud support **6**

Sensitization time t of special-grade stainless steels with different carbon contents C at temperatures T **7**



The results of this activity influenced the choice of repair method and materials employed in the Oskarshamn 1 retrofit. It was decided, for example, in the case of the core shroud support replacement to use nuclear grade stainless steel (316 NG) instead of the original 304 grade steel. The nuclear grade steel chosen has a carbon content of less than 0.02 percent, so that the prevailing water chemistry constitutes no risk to the material **7**.

New options for older reactors

As the inspections and repair work carried out in the 20 years old Oskarshamn 1 nuclear reactor have shown, a reactor pressure vessel can be cleaned and the radiation dose rate lowered to a level at which work can be carried out safely by fitting a customized radiation shield.

The inspections further showed that the pressure vessel itself is still intact after 20 years in service and shows no sign of abnormal wear.

By employing materials specially suited to a nuclear environment when replacing core internals and piping, such repairs contribute to an improvement in the operational reliability of the plant and extend its lifetime. The work performed in Oskarshamn 1 nuclear power plant has demonstrated that this is technically possible.

Authors' address

Niclas Säll
Tore Waltersten
ABB Atom AB
S-72163 Västerås
Sweden
Fax +46 21 18 86 93