Ageing aspects of Concrete Containments from a Regulatory Point of View

Behnaz Aghili[1]
[1] Department of Reactor Technology and Structural Integrity, Swedish Nuclear Power Inspectorate, SKI

ABSTRACT

Operating nuclear power plants the world over are getting older. This is also true for Swedish nuclear power plants which were constructed during 1960-s and 1970-s. Following a referendum in 1980, nuclear power was expected to be phased out by 2010 in Sweden. Ageing issues for different constructions and components are of concern since these power plants are expected to be in use for longer period than they were originally designed for; around 40 years. To be able to maintain high safety level, at least to the same extent as today, some issues need to be considered.

Ageing management for different parts and components in a nuclear power plant can be carried out in different ways. Some parts or components are easy to repair or replace and will be repaired or replaced when defects or degradation are a fact. Others are more difficult to repair, or impossible to replace, such as the reactor pressure vessel and containment buildings. It is therefore very important to have good knowledge of the condition of these structures or components and different possible degradation phenomena which can lead to unacceptable changes in their characteristic properties.

Some national and international incidents, as well as an introductory investigation made by the Swedish Nuclear Power Inspectorate, SKI, [4], pointed to the some areas of concern for containment structures. Research projects during last few years have been related to these areas. These projects, their outcomes and future work from a regulatory point of view are discussed in this paper.

CONTAINMENT BUILDINGS IN SWEDISH NUCLEAR POWER PLANTS

Two different types of reactors – boiling water reactors (BWR), and pressurised water reactors (PWR) – are operating in Sweden.

All the containment buildings in Swedish NPPs are built using pre-stressed concrete. The pre-stressing tendons, aimed at supporting the tensile loads that arise in the event of an accident, are placed in liners filled either with grease or cement, or ventilated with dry air to protect them from corrosion. The cylindrical walls of the containments were cast in two concentric shells. The containment building is also reinforced with reinforcing steel. A steel liner, embedded into the concrete to provide leak tightness in the event of an accident, lies between the two concentric concrete shells, and is made of carbon steel or stainless steel (Figure 1).

In any event, containments must maintain their leak tightness to protect the public and the environment from radiation. To fulfill this requirement, the design of containment incorporates measures that prevent plastic deformation of reinforcing steel, crack formation in concrete, loss of pre-stressing force, and significant damage such as holes in the embedded liner.

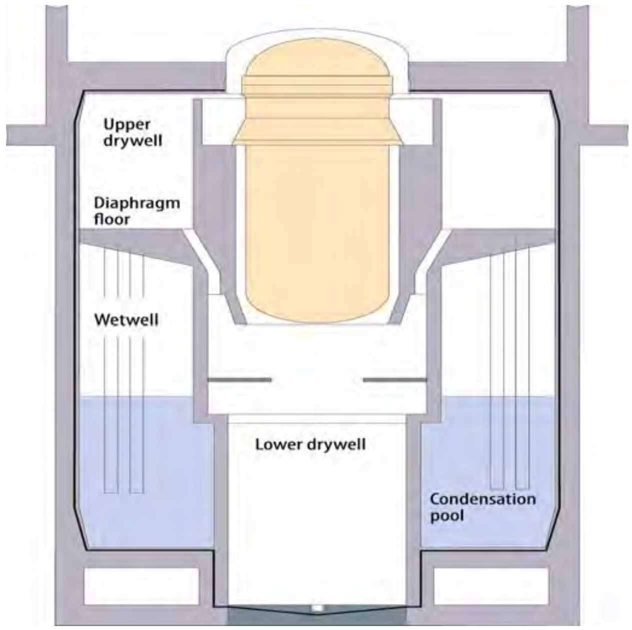

Figure 1: Principal of the containment building for a boiling water reactor.

DEGRADATION PROBLEMS OCCURRED IN SWEDISH NPPs

Although certain safety factors have been achieved during the design and construction of containments, the safety of containments can still be affected adversely by age-related degradation of containment materials. In this respect, serious incidents have been reported by Forsmark 1 (1997), Barsebäck 2 (1993) and Ringhals 2 (2004), involving corroded liners and seals, degrading the leak tightness of the containment. All these events were related to installation work which was not in accordance with the design drawings. Corrosion has been the dominant damage mechanism.

Forsmark 1

The damage in Forsmark 1 was discovered during a leak test of the containment, when leaks were found in both an outer and an inner seals (Figure 2). These were removed for further inspection. It was then found that corrosion had occurred as a result of moisture inside the insulation. A plastic film, intended to protect the insulation from moisture, was discovered. On removal of this a considerable amount of water was released.

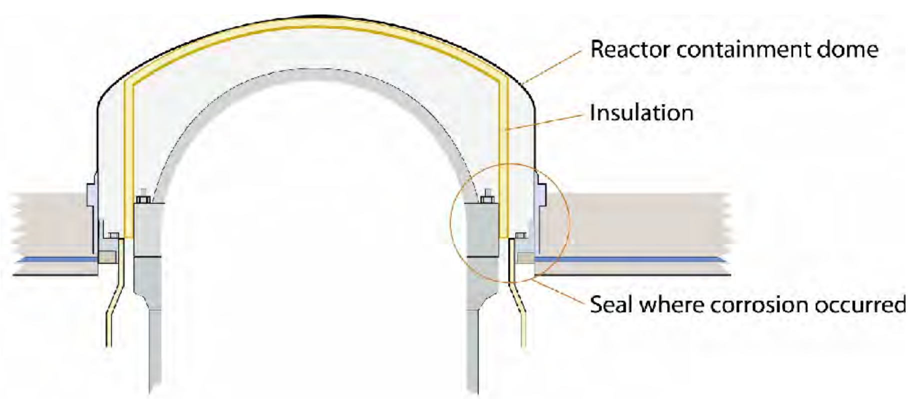

Figure 2: Location of the damage discovered at Formark 1.

Barsebäck 2

The damage at Barsebäck 2 was also discovered during a leak test. Investigation revealed corrosive damage to the liner. This had resulted from an incorrect refilling of a cavity around a pipe penetration where water had been allowed to remain (Figure 3). When the cavity was to be refilled with concrete, containing a swelling agent, this later reacted with the water producing porosities in the concrete. Furthermore, the cavity had only been partly filled in, and in this environment corrosion ensued.

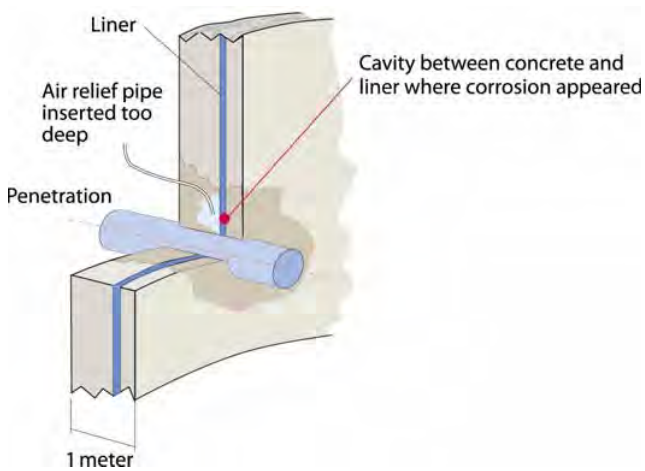

Figure 3: Location of the damage discovered in Barsebäck 2.

Ringhals 2

The damage at Ringhals 2 was discovered during a routine leakage control. Investigations revealed excessive corrosive damage to both inner and outer seal sheets which connected the liner located in the ground to the liner located in the concentric wall of the containment. Water with high pH had been injected between the two seal sheets to avoid corrosion. Investigations revealed that the amount of water had been varying during the time and sludge of cement containing high amount of silicon was remained on the seal sheets and had contributed on the corrosion damage (Figure 4 and 5).

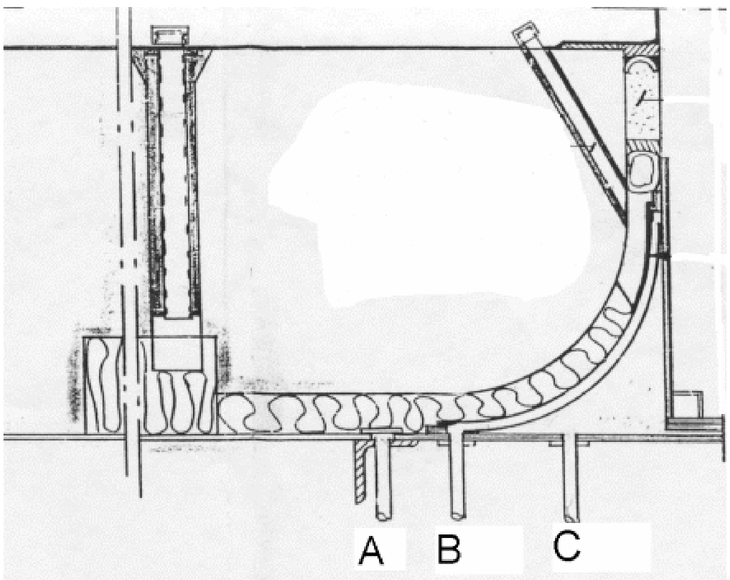

Figure 4: Location of the damage discovered at Ringhals 2.

Figure 5: Corrosion damage at Ringhals 2.

Other incidents

Other incidents which can be mentioned here are: accumulation of water between the seal and concrete at Forsmark 3, water inside the containment liner at Ringhals 2, holes in the roof plating at Oskarshamn 1, erosion of the exterior concrete of the containment at Ringhals 3, damaged pre-stressing cables at Forsmark 3, and the so called "plug" at Barsebäck 2 – the result of an incorrect drilling into the floor framing, (Figure 6).

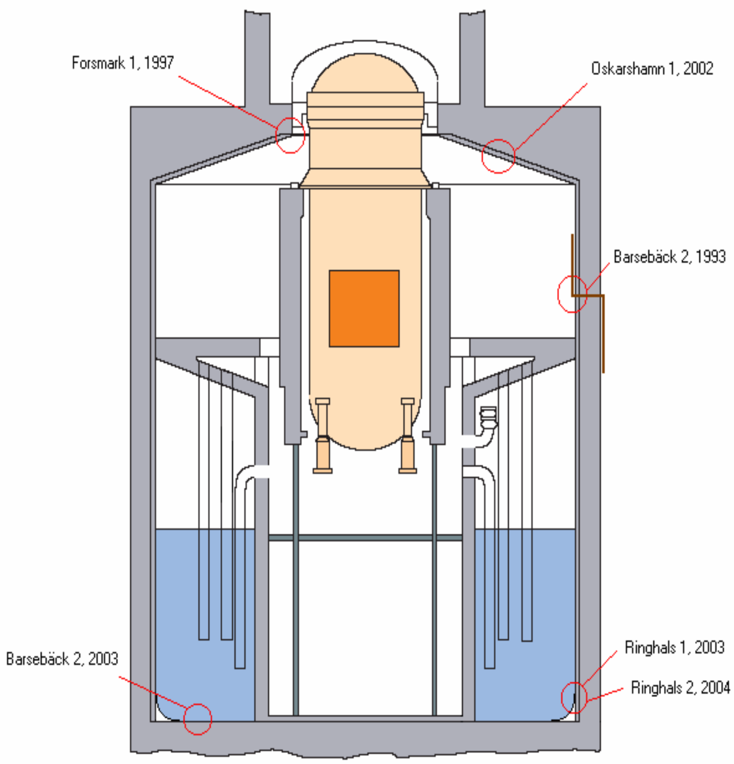

Figure 6: Location of discovered damages in different containment buildings in Swedish NPPs.

In summary it can be seen that in the main the major incidents that have occurred have been the results of installation work not done in accordance with the design drawings. Corrosion has been the dominant damage mechanism.

RESEARCH PROJECTS FOCUSED ON FIVE AREAS OF CONCERN

The aforementioned incidents in Sweden and some others abroad as well as exploratory investigations performed by the Swedish Nuclear Power Inspectorate [4] pointed to five main areas of concern: the degree of relaxation of the pre-stressed tendons; corrosion of pre-stressed tendons; corrosion of embedded liner due to installation work not in accordance with drawings; the ability to investigate the liner; and the condition of the concrete itself. The research projects performed by SKI and Swedish utilities over the past five years have addressed these issues.

In particular, the condition of pre-stressed cables and the degree of relaxation in them were studied in a PhD thesis, whereas other projects were dedicated to surveying the condition of the concrete and the embedded metallic parts (liner, reinforcing steel) after 30 years of service. The project termed “Material investigation of the containment of Barsebäck 1” was thus carried out on the containment building of Barsebäck 1, and the EU-funded project “CONMOD” was aimed at finding a system to maintain the safety of containment over the entire lifetime of the plant. This project was also a screening work to assess the ability of different non-destructive evaluation (NDE) methods to investigate flaws and degradation in thick concrete constructions. The critical areas identified thanks to the finite element analysis (FEA) were thus investigated using different NDE-methods to detect if the containment had been constructed in compliance with drawings and if flaws or corrosion could be detected, [3].

Pre- stressed tendons are the most vital design elements in determining the ability of the containment to fulfil its function. Information as to the possible relaxation of these tendons and their degree of relaxation together with their possible corrosion is therefore very important. The PhD thesis revealed that the degree of relaxation in the pre-stressed tendons embedded in grease was lower than expected, [2]. This is in agreement with results from other research project pointing to low creep and shrinkage of the concrete in containment buildings, [1].

The containment building of the boiling water reactors (BWR) in contract to containment building of pressurised water reactors (PWR), are situated entirely within the plant building. This means that they are not liable to damage by external factors, such as water, moisture or airborne contaminants, leading to carbonisation, frost, abrasion or erosion damages. On the other hand, the containment building for the pressurised water reactors (PWR) are exposed to these elements. In order to judge the risk for leaching, sulphate, acidic or basic attack it is necessary to have knowledge of the quality of the cement and its water content.

Recent studies performed on the containment building of Barsebäck 1 show that high quality concrete has been used, and the condition of the concrete is very good after 30 years service. No serious degradation mechanism, or at least no serious damages which can be related to degradation processes, has been identified for the concrete in the containment building of Barsebäck 1, [1].

The degree of carbonisation and chloride diffusion were also found to be very limited. Humidity measurements showed that the concrete still had high moisture content, [1]. This means that shrinkage and creep have not been serious, which also partly explains the low relaxation rates in pre-stressed cables embedded in grease measured in other projects, [2].

In general the temperatures in the containments lie around 60 °C, although somewhat higher temperatures can occur locally, such as in the vicinity of certain penetrations. In recent research programmes some of these areas have been investigated. The concrete has lower moisture content in areas exposed to higher temperature but even in these areas the moisture content is still higher than expected, [1].

These results are very promising, but one must bear in mind that the investigations are made on a single containment, and are very limited, and there are still some unanswered questions about the construction of the containment.

Irradiation and corrosion are two possible mechanisms for damage of reinforced steel. The reinforcements are embedded deeply in the concrete, and irradiation should not be a problem. Results of recent research show that neither corrosion, due to carbonisation, nor diffusion of chlorine ions is of such an extent as to threaten the containment function, [1].

Although corrosion of the embedded liner is a possible scenario, general corrosion of these components are not of concern. Assuming that the designs follow applicable regulations, and that the specifications are adhered to, even localised corrosion should be avoided because steel is in a passive condition in the basic environment provided by concrete. Unfortunately it has been proved necessary to investigate localised corrosion, in the light of the cases that have occurred both in Swedish reactor plants and in other plants and the results from the recent research programme, [1]. The underlying cause behind these cases is non-compliance with the design specifications. This has led to deviations in the local environment with an increased risk for corrosion, and subsequent degradation of the leak-tightness function of the containment. The conclusion is also valid for pre-stressed liners which are embedded in cement.

Two pipe penetrations were investigated as part of the CONMOD-project and both of them showed non-compliance with valid drawings, [3]. The conclusion is any how that if the construction is in agreement with valid drawings, the risk for corrosion of embedded metallic parts, i.e. liner, is minimal [3].

CONCLUSIONS AND FUTURE WORK

SKI-s preliminary conclusion is that to be able to have a valid assessment of the condition of the containments, every plant needs to determine which deviations from drawings might exist in the containment buildings and how these deviations might have affect the integrity of the containment. A management programme is needed for every plant in which the methods to investigate such deviations and to detect and repair eventual defects are described. Areas of special interest are pipe penetrations and pre-stressed tendons embedded in cement.

The degree of irradiation in some parts of containment and in which degree it would affect the characteristics of the concrete, is not clearly understood. This question needs to be addressed in future work.

Pre-stressing tendons forms a vital element of the functioning of the containment structure and a study of the possibilities for determining the status of tendons embedded in cement, using some form of non-destructive inspection method, is called for in future work.

REFERENCES

1. Joval, O. (2005), *Barsebäck NPP – Reactor containment, Material testing project: Summary report,* Scanscott Technology AB

2. Andersson, P. (2005), *Evaluation of the prestess level in nuclear reactor containments*, Report TVBK-1029, Division of Structural Engineering, Lund Institute of Technology, Lund University

3. Force Technology (co-ordinator)/Scanscot Technology/Electricité de France, EDF/Barsebäck NPP, CONMOD – *Synthesis report: Concrete containment management using the Finite Element technique combined with in- situ Non-Destructive Testing of conformity with respect to design and construction quality*, Euratom contract No FIKS-CT 2001-00204

4. Barslivo, G., Österberg, E., Aghili, B., SKI – Report 02:58, *Investigation of reactor containment buildings – construction, degradation problems and testing and maintenance (In Swedish),* Swedish Nuclear Power Inspectorate