Climatic conditions at the surfaces of concrete containments – examples for two BWR and PWR reactors

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ABSTRACT

The climatic conditions at the concrete containment wall surfaces of two nuclear reactor containments were examined and quantified as a basis for predicting the drying process. Two types of nuclear reactor containments were studied, for a BWR reactor and a PWR reactor in Sweden**.** They both have a thick concrete wall with a steel lining inside, but the BWR containment walls are enclosed in a building, protecting it from the outdoor climate. The PWR containment walls are exposed to outdoor weather conditions. The conditions inside the containment walls include high temperatures, up to around +50°C. Measurements of temperature and relative humidity (RH) in the outdoor air and in various points at the surfaces were used to evaluate the vapour contents of the air and in the concrete surface. By comparing the vapour contents in different points a method was developed that can be used for predicting the previous and future surface climate at the containment walls.

Two major differences between the two types of reactors are the presence of significant temperature gradients between the outer and inner wall surfaces in the PWR reactor that are missing in the BWR reactor and an exposure to outdoor climate of the PWR containment walls. In both types of reactors there are large temperature differences at different levels. The consequences of these conditions are major differences in surface humidity, from below 20 % RH in the upper parts of the BWR containment wall in wintertime to some 70-80 % RH in the outer parts of the PWR containment walls. The previous and future surface climate conditions can be predicted from outdoor climate data and the temperature conditions measured during a short term study.

INTRODUCTION

For most ageing processes in reinforced concrete structures the moisture conditions are important and often decisive [1][2]. In nuclear reactor containments the moisture conditions in the concrete will mainly affect the shrinkage and creep of the containment walls and, as a consequence, the stress losses of the prestressing reinforcement [3]. For the possibility, and rate, of metal corrosion the moisture conditions are also decisive [2]. The drying process and the possible extent of drying depend on the boundary conditions, i.e. the relative humidity at the surfaces.

The first series of measurements of these climatic conditions were performed on a running BWR reactor, at the outer surfaces of the containment wall [4]. The general layout of the reactor containment is shown in figure 1. Temperature and relative humidity (RH) were recorded during several months at the concrete surfaces and in the outdoor air. The measuring points are shown in figure 1.

The temperature and humidity were used to calculate the vapour concentration of the air in the measuring points. By comparison, the vapour concentrations were found to be very close to the vapour content in the outdoor air. Consequently, the previous and future climatic conditions at the surfaces of concrete containment walls are well predicted from weather data, giving the vapour content of the outdoor air, together with the outer surface temperatures at different parts of the containment walls. From the vapour contents and the surface temperatures, the relative humidity at the surfaces can be calculated. At a parallel, recently closed reactor, cores were taken to measure the humidity profiles in the concrete wall, see figure 1. The outer part of these profiles coincided very well with the predicted RH at the surfaces [4].

From the measurements it was clear that the BWR containment walls do not have a significant temperature gradient, not even at the top of the containment, where inside temperatures reach some +50°C. It was also clear the concrete surfaces are very dry, below 15 % RH at the top.

Two other nuclear reactor containments were now studied, for a BWR reactor and a PWR reactor at the Ringhals nuclear power plant at the west coast of Sweden**.** They both have a thick concrete wall with a steel lining inside, but the BWR containment walls are enclosed in a building, protecting it from the outdoor climate. The PWR containment walls are exposed to outdoor weather conditions. The conditions inside the containment walls include high temperatures, up to at least +30-35°C. Measurements of the temperatures inside the containment walls are currently performed.

The general layout of the two types of reactor containments is shown in Figure 1 and 2.

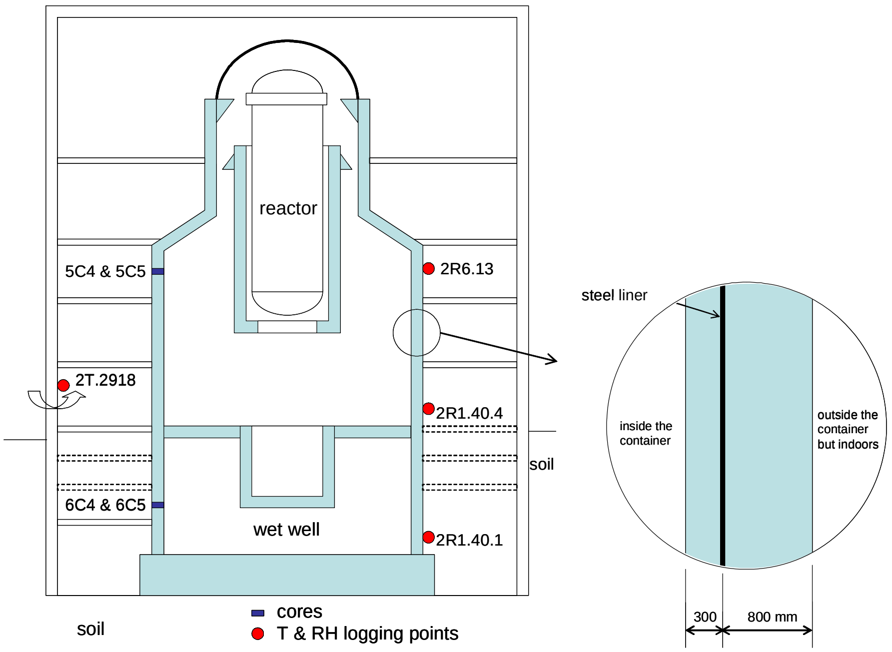

Fig. 1 A general layout of a BWR containment with the measurement points (T, RH) and the coring points in a previous study [4] and a cross section detail of the wall showing the steel liner position.

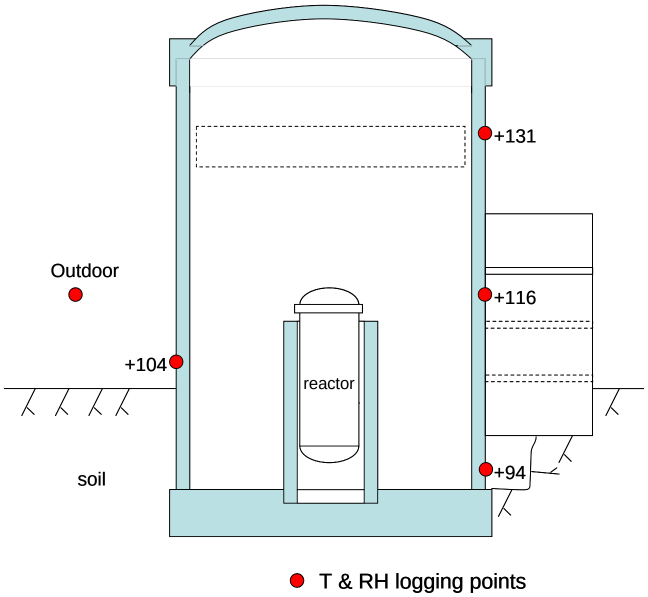

Fig. 2 A general layout of a PWR containment with the measurement points for (T, RH)

THE BWR REACTOR CONTAINMENT

Now, similar measurements as in the previous study were done at the outer surfaces of the BWR reactor containment R1, with the same general layout as the previous one, cf. figure 1.

Measurements

The temperature and RH were measured by a data logging system in the same way as in the previous study [4]. The loggers were calibrated in a Thunder precision moisture chamber and were placed at the outer surface of the containment wall in different positions around the containment and at different levels. One data logger was placed outdoors under a roof to give the vapour content of the outdoor air.

Results and Analysis

From figure 3 it is seen that the surface temperature outside the containment wall in the upper part of the containment is close to 30-35°C during service (point +115). The relative humidity at the outside concrete surface is extremely low during this period, between 15 and 30 % RH during service, cf. figure 3. Similar results were found in the other four points, with corresponding RH being 20-40 % at 25-28°C (+100, +120) and 40-60 % at 20°C (+87). The RH at the outer surface is obviously very different at different levels and orientations.

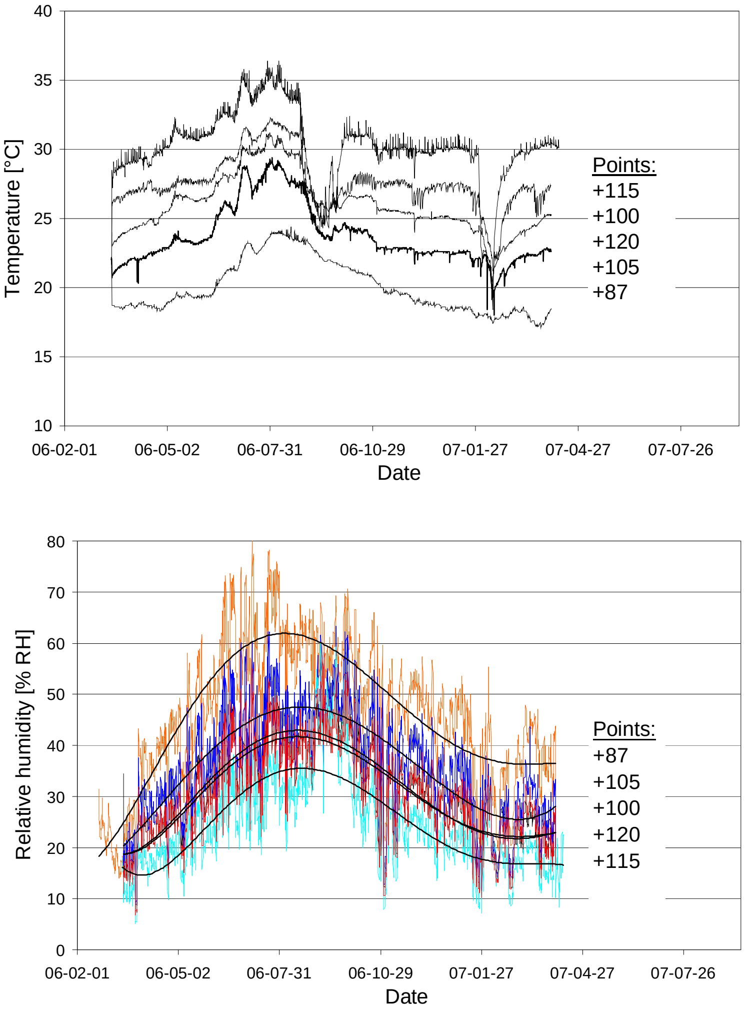

Fig. 3 Temperature (top) and RH (bottom) at the outer surfaces in five measuring points, BWR reactor R1

From the temperature and humidity measurements the vapour content can be calculated. The results are shown in Figure 4 for all five points, with a comparison with the vapour content of the outdoor air. The vapour contents of the air close to the concrete surfaces, with very different temperatures, follow the vapour content of the outdoor air closely, with only small differences, less than 1 g/m^3, as seen from the differences between the trendlines.

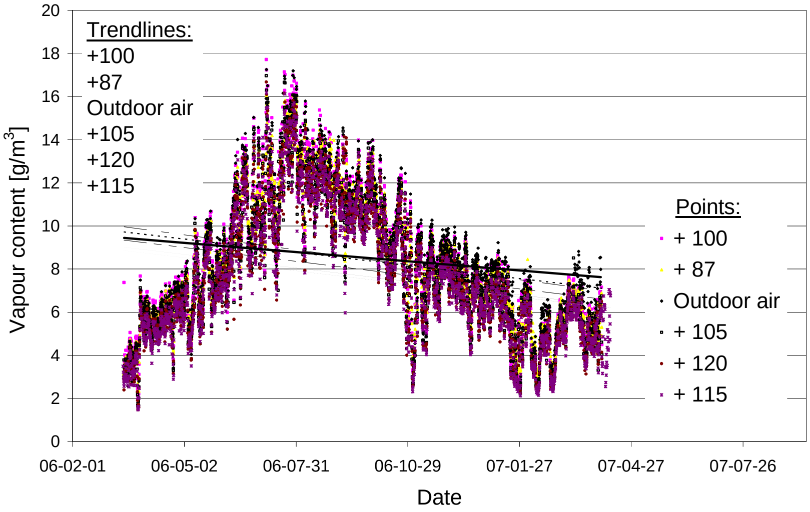

Fig. 4 The calculated vapour contents at the outer surfaces in five measuring points, BWR reactor R1

When the plant was temporary out of service, in the middle of the period, RH increased to some 40-50 % because the temperature fell to some 22-23°C, see figure 5 for point +115. The vapour content does not change but follows the vapour content of the outdoor air.

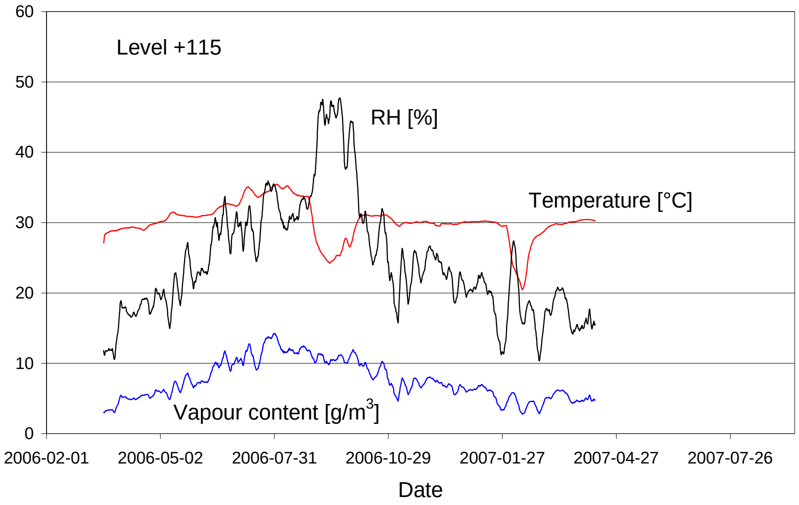

Fig. 5 The calculated vapour contents at the outer surfaces in five measuring points, BWR reactor R1

The previous and future climatic conditions can then be predicted only by using weather data, assuming the same moisture supply in the building as during a short measuring period. From the predicted vapour content of the indoor air, which also is the vapour content close to the outer surface of the containment wall, the relative humidity RH at the surfaces can be predicted.

$$RH_{surface} = \frac{v_{outdoor\ air}}{v_s(T_{surface})} \tag{1}$$

This confirms the results of the previous study [4], for BWR reactor containments that are not exposed to outdoor climate and that are well ventilated, giving a negligible moisture supply of less than 1 g/m^3. The main difference between the two studies of BWR containments is the maximum temperature inside the upper part of the containment. That difference explains why the surface RH was lower in the previous study.

THE PWR REACTOR CONTAINMENT

For a PWR reactor containment temperature gradients over the containment walls are expected periodically since they are exposed to outdoor conditions with low temperatures during the winter. Additionally, the exposure to outdoor climate should give much higher RH than for BWR reactor containments.

Measurements

Measurements were performed at the containment for the PWR reactor R3 at Ringhals, next to the BWR reactor R1 at the same plant. The measurements at the outer surfaces were done with a different technique since the data loggers used for the BWR reactor containment cannot be exposed to rain. In drilled holes Vaisala RH-probes were inserted into PVC-tubes that end at a depth of some 30 mm from the outer surfaces. Because of the temperature variations from solar and long-wave radiation, wind and rain, the temperature is measured in each measuring point at the RH-sensor and in the concrete where the RH is to be estimated. Between these two points a temperature difference is expected which makes the RH at the sensor different from the RH in the concrete. To limit the temperature differences, the PVC-tubes and the cables were painted in the same colour as the surrounding concrete surfaces.

An example of the temperature measurements is shown in figure 6, as the temperature difference between the concrete and the RH-sensor at a depth of 30 mm. The temperature difference is about 1.5°C as an annual average.

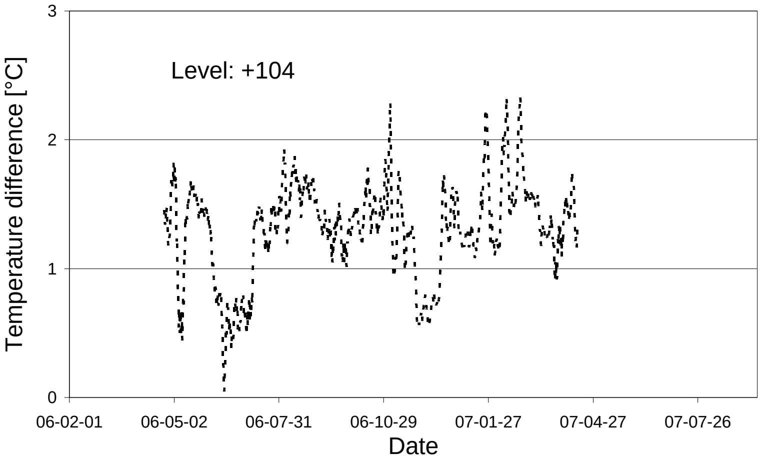

Fig. 6 The difference between temperatures measured directly in the concrete and at the RH sensors. Both temperatures were measured at a depth of 30 mm from the outer containment surfaces of PWR reactor R3

Results and Analysis

The results of the temperature measurements in the concrete are shown in figure 7 for two points at the outer surface, +104 (facing north) close to the ground and +131 (facing wets-south-west) in the upper part of the wall. The outdoor temperature is shown for comparison. The temperature of the concrete is always a few °C higher than the outdoor temperature.

The vapour content of the concrete at a depth of 30 mm was calculated from the measured temperature and RH at the sensor, which is very close to the concrete in the measuring point. The results are shown in figure 8 for the two points, with the vapour content of the outdoor air as a comparison. The vapour content in the concrete is higher than in the outdoor air during the warm part of the year, i.e. the concrete surface is drying out. During the early winter the vapour content of the outdoor air is higher than the vapour content of the concrete. During that period the concrete surface is humidified by moisture from the outdoor air.

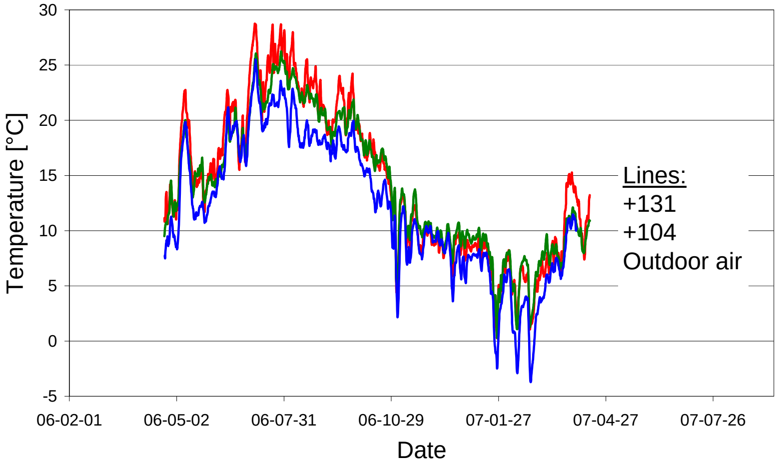

Fig. 7 The measured temperatures at a depth of 30 mm from the concrete surfaces of PWR reactor R3

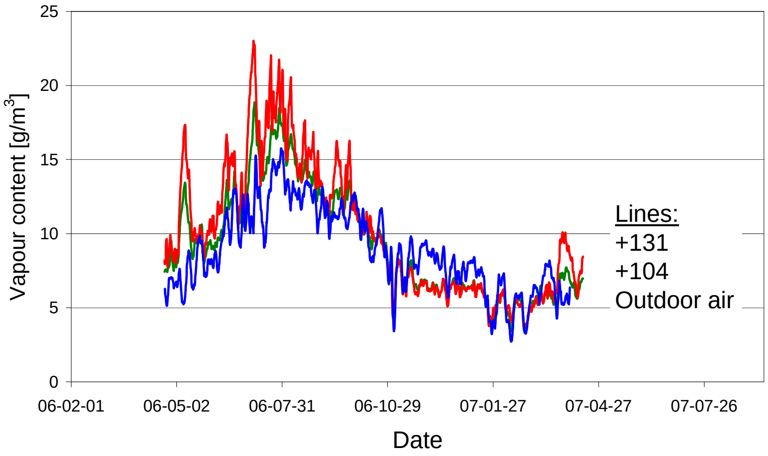

Fig. 8 The vapour contents at a depth of 30 mm from the outer concrete surfaces of PWR reactor R3 calculated from measured temperatures and RH at the sensor

The relative humidity of the outdoor air and the concrete at a depth of 30 mm is shown in figure 9. The RH in the concrete was calculated from the vapour content at the sensor, cf. figure 8, and the measured temperature in the concrete.

$$RH_{concrete} = \frac{v_{sensor}}{v_s(T_{concrete})} = \frac{RH_{sensor} \cdot v_s(T_{sensor})}{v_s(T_{concrete})} \qquad (2)$$

As seen from figure 9, the concrete RH is very stable during a year with only a small drop in RH from drying during the summer and a small RH-increase during the winter. The annual variation is small, however, within 70-80 % RH in the two points. The RH in the outdoor air is 90-100 % during part of the winter but the wetting of the concrete is extremely slow and very little moisture transport is reaching a depth of 30 mm.

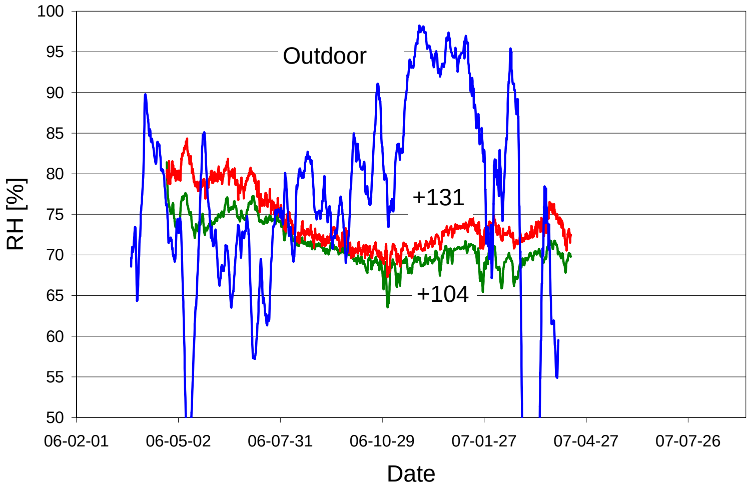

Fig. 9 The RH at a depth of 30 mm from the outer concrete surfaces of PWR reactor R3. The concrete RH is calculated from measured temperatures and RH at the sensor

Results and Analysis, surfaces not exposed to outdoor climate

Measurements in the two points that are not exposed to outdoor climate were performed by the same type of data logging system as used for the BWR containment. The result of the measurements is shown in figure 10, as vapour contents in the two points compared to outdoor air.

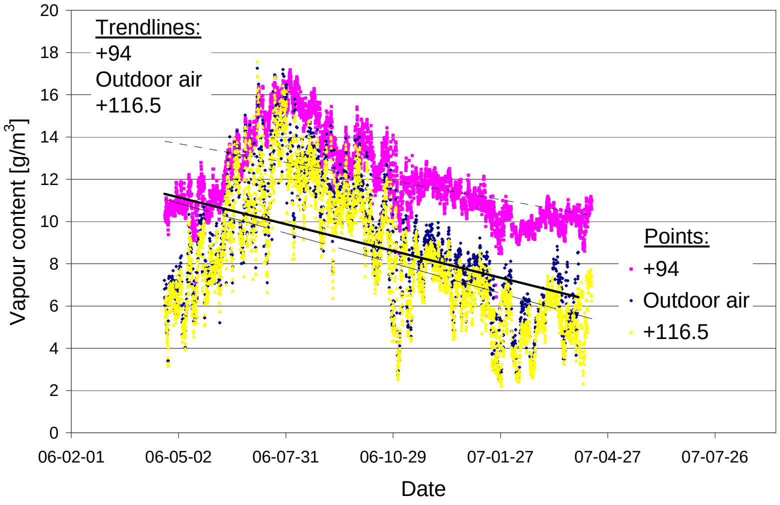

Fig. 10 The vapour contents at the outer concrete surfaces of PWR reactor R3.

At the concrete surface inside the building that is connected to the containment wall (point +116), the vapour content is very similar to the conditions in the outdoor air. Consequently, the moisture supply in that building is small, most probably because of good ventilation and no major source of moisture.

The conditions are quite different in point +94, however. This point is below ground, in a space directly exposed to open faces of soil rock. The moisture balance, i.e. the balance between the moisture supply from the soil rock and the ventilation, gives a moisture supply of some 3-4 g/m^3. The climatic conditions of surfaces in that type of space must be separately quantified by studying the moisture balance and identify the sources of moisture.

CONCLUSIONS

Two major differences between the two types of reactors were found. There are significant temperature gradients between the outer and inner wall surfaces in the PWR reactor containment walls that are missing in the BWR walls. The PWR containment walls are exposed to outdoor climate. In both types of reactors there are large temperature differences at different levels. The consequences of these conditions are major differences in surface humidity, from below 20 % RH in the upper parts of the BWR containment wall in wintertime to some 70-80 % RH in the outer parts of the PWR containment walls.

The previous and future surface climate conditions can be predicted from outdoor climate data and the temperature conditions measured during a short term study by assuming an equal vapour content in the outdoor air and the air next to the outer concrete surfaces of the containment walls.

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NOMENCLATURE

BWR = Boiling Water Reactor
PWR = Pressurized Water Reactor
RH = relative humidity
T = temperature
v = vapour content of air or concrete pores
$v_s(T)$ = vapour content at saturation at temperature T

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