THE SCANDINAVIAN PCRV MODEL PROJECT: THERMAL INSULATION TESTS

W. KRAEMER.
ASEA-ATOM, Västerås
S. MENON, G. HERNBORG, B. JOHNSON,
AB Atomenergi, Studsvik, Sweden

ABSTRACT

The paper describes some of the insulation tests carried out under a joint development programme by Denmark, Finland, Norway and Sweden in the field of prestressed concrete reactor vessels for water reactors. The Scandinavian PCRV concept is characterized by a removable insulation, allowing for erection of the insulation outside the pressure vessel, for repair of the insulation if serious defects should arise after many years of operation and for inspection of the vessel liner. The insulation, as well as the space between the insulation and the vessel liner, are filled with gas or alternatively with water.

A multipurpose test facility has been built in Studsvik, Sweden, mainly for testing the novel designs of the removable lid and of the insulation systems. The model vessel is approximately to scale 1:3.5 relative to a reactor vessel for an 800 MWe BWR. The vessel is insulated by stainless steel insulation of the 'Metalisol' type (from France). It is bolted on to the outside of a removable 'casing', which encloses the reactor internals. The model can be pressurized either by cold or hot water or by saturated steam up to 85 bar (300 deg. C). There are various other auxiliary systems for level control, lining cooling, etc.

A first test series was concluded in December 1970. This series included operation at service conditions (70 bar, 285 deg. C) and at design pressure (85 bar, 300 deg. C) with gas and water-filled insulation, tests with vessel pressure oscillations, transient tests including fast depressurization of the steam dome or sudden flooding of the insulation system with hot water near saturation temperature. The excellent performance of the insulation system is demonstrated by typical 'temperature maps', print-outs of the data reduction programme developed for the evaluation of the thermal insulation tests.

A second series is now being planned.

1. INTRODUCTION

Studies carried out in Sweden in the middle sixties had shown that Prestressed Concrete Reactor Vessels (PCRV's) were technically and economically feasible for water reactors. Development work initiated in 1967 on a Scandinavian basis resulted in a vessel design with a removable lid and a removable insulation. For the purpose of testing and demonstrating the feasibility and behavior of these designs under normal and emergency conditions, a model project was launched with participation from Denmark, Finland, Norway and Sweden.

2. THERMAL INSULATION PRINCIPLE

The load carrying structures of a PCRV must be kept at acceptable temperatures (normally between 40 and 80 deg. C at the inner face) by means of a thermal insulation. Various principles for the thermal insulation lay-out of a water reactor PCRV are illustrated in figures 1-3. Deviations may exist between different designs i.e. as regards insulation material for the same basic principle.

The insulation system developed in Scandinavia for a boiling water reactor (BWR) with PCRV is illustrated in figures 3 and 4. A permeable thermal insulation structure is fitted on the outer surface of a removable 'casing', in the form of an inverted cup which encloses the reactor internals. Since the casing is removable the insulation can be mounted outside the pressure vessel and the possibility exists to remove and repair the insulation, if a failure should occur after many years of reactor operation. At the bottom corner the casing together with an inner baffle forms a water seal which automatically equalizes the pressure between the steam dome and the insulation space even during fast pressure transients.

The insulation gap between the casing and the vessel liner is filled with gas or alternatively with water. The gas or water within the porous metallic insulation structure is almost stagnant, which provides for favourable insulation properties. Turbulent free convection is established in the gap between insulation and liner. This provides an effective means of suppressing the propagation of eventual local insulation 'hot spots' to the liner.

For the Scandinavian model vessel the French insulation 'Metalisol' has been chosen.

In order to avoid a high partial H_2O steam pressure within the insulation gas space and thereby condensation on the vessel lining or insulation, the water lock is equipped with a cooling system, which keeps the water lock temperature normally between 40 - 75 deg. C.

On the side walls of the PCRV, cooling tubes are fastened to the concrete side of the liner. The system removes the heat losses of the thermal insulation and the γ-heat generated in the concrete vessel.

3. THE STUDSVIK PCRV MODEL

3.1 Description of Model Vessel

The Studsvik model vessel is a multipurpose test facility mainly for testing the designs of the removable lid and the insulating systems. Normal BWR service conditions (70 bar, 285 deg. C) as well as, within certain limits, postulated accident conditions can be simulated in the model. A vertical section through the model is shown in fig. 5.

The diametral scale of the model is approximately 1:3.5 relative to the reactor vessel for an 800 MWe BWR. The inside dimensions of the cylindrical model are 2 m diameter x 4 m height. The vessel has a design pressure of 85 bar which gives it a minimum wall thickness of 1.1 m. The vessel and the lid are lined by a 10 mm stainless steel/mild steel lining, which is keyed into the concrete by welded-on studs.

The basic elements of the 'Metalisol' insulation are tight mesh screens, woven from 0.2 mm thick stainless steel wires. A pile of about 20 screens forms one 'mattress'. The insulation is built up by 4-5 mattresses separated from each other by 0.2 mm thick overlapping stainless steel sheets. The porous insulation structure suppresses the natural convection of gas or water to a great extent. The outer side of the 25 mm thick insulation structure is protected by 5 mm thick cover plates.

The bottom insulation is permanently water-filled. Due to the 'natural' temperature gradient within the bottom insulation, a stable stratification effect exists which allows for more robust insulation design of the bottom insulation. In the Scandinavian model vessel the screens on the bottom insulation are woven from 0.5 mm stainless steel wires. The thickness of the bottom insulation is about 100 mm.

3.2 Auxiliary systems

The model can be pressurized by either cold or hot water or by saturated steam up to 85 bar. The cold pressurizing system can take the model up to 215 bar. During the insulation tests, the vessel is taken to service conditions by steam being supplied into the steam dome over the water surface in the vessel. Cold water is sucked out from the bottom of the vessel and sprayed into the steam dome, thereby bringing the whole water/steam space to saturation or near saturation temperatures.

For the insulation tests, the steam is produced in an external electric steam generator. There are systems for level control (both in the vessel and in the water lock), cooling systems, etc. The lining cooling systems are served by two pumps which can be connected either in series or in parallel.

3.3 Instrumentation

The model is instrumented for the measurement of temperatures on the inside of the casing, on the cold face of the insulation as well as on the concrete side of the lining. The lining thermocouples are placed on the concrete side half-way between two adjacent cooling pipes, where the local max. temperature of the lining can be expected. Other values measured are the temperatures in the water lock, 'in' and 'out' temperatures and flows in the various cooling circuits, power consumption, etc. Most of the measured temperatures are recorded by means of a 200-channel data-logger on punched tape.

During certain tests two 12-channel temperature plotters were used in order to continually follow selected insulation and lining temperatures. During the transient tests, there was continuous pressure recording as well.

3.4 Computer programme for evaluation of test results

In order to facilitate presentation and evaluation of the test results, a computer programme was developed, handling the great number of data recorded at every test condition. The programme has several options for presenting the test results. For example, a schematic vertical section of the insulation system in the model vessel can be plotted together with a print-out of the measured temperature distribution of the vessel liner and the thermal insulation. These temperature 'maps' have been very useful not only as a surveyable presentation of test results but also as a fast feed back to the actual experiment.

In the following the insulation test results will mainly be presented in form of temperature maps, which are based on print-outs of the evaluation programme.

4. INSULATION TESTS

The history of tests performed on the insulation is shown in fig. 6. The test programme started with gas-filled insulation, after which water-filled insulation was tested. Finally the test series was terminated by the simulation of a number of accident situations. The tests with water-filled insulation were time-consuming as the auxiliary systems had to be modified on several occasions in order to satisfy the widely-varying requirements for the various tests.

4.1 Test with gas-filled insulation

During April 1970 the first long-term test under BWR service conditions at 70 bar steam dome pressure and 285 deg. C steam temperature was performed.

The interface between insulation gas (N_2) and waterlock was set about 0.4 m above the vessel bottom liner. As mentioned earlier the interface was cooled by spray cooling and the level controlled by the insulation gas system, which automatically corrects the amount of gas in the insulation gap, if the waterlock level exceeds preset limits.

The heat losses of the thermal insulation were removed by the liner cooling circuits. During the gas-filled insulation tests only one of the two parallel lining cooling systems on the side walls and on the lid were used. Thereby the pitch of the active cooling pipes was 120 mm.

After about 10 days waiting to reach steady state, a temperature distribution as shown in fig. 7 was recorded. The figure is based on the temperature map plotted by the evaluation programme. The insulation system is not shown to the correct scale.

The measured lining temperatures are all close to 50 deg. C with small variations. The average hot and cold side temperatures of the thermal insulation (excl. bottom insulation) are 283 and 71 deg. C respectively.

A local temperature increase (85 deg. C) can be seen at the upper corner of the insulation. This small 'hot spot' can be explained by convection effects. It should be mentioned that the upper insulation corner was not carefully designed. Of special interest, however, is the fact that a corresponding temperature increase cannot be seen in the liner opposite to the insulation hot spot.

The local liner temperature profile between two active cooling pipes can be studied from the readings of some special thermocouples (circled in fig. 7). These show a temperature of 50 deg. C half-way between two active cooling pipes and 48 deg. C within the weld of the adjacent cooling pipe. The temperature variations between two adjacent cooling pipes are remarkably low in comparison with the variations reported from gas-cooled reactors with insulation directly mounted on the lining.

The waterlock was effectively cooled by the spray system as indicated by the recorded temperatures within the waterlock and the annulus leading upwards to the saturated water of the vessel. The thermal gradient near the bottom weld of the inner water seal baffle is low, which reduces the thermal stresses at the bottom weld to a minimum.

The water within the vessel was kept at near saturation temperature by means of a special circulating system. The outlet of the circulating system was placed about 30 cm above the bottom insulation (the torus-shaped outlet pipe can be seen in fig. 5). With this configuration the 'hot' side temperature of the bottom insulation was only about 57 deg. C. This low temperature can be explained by the natural stratification of the water layer between the bottom insulation and the circulation pipe outlet. The stable water layer acted itself as a thermal insulation.

During later tests the circulation system was modified allowing for circulation of hot water along the bottom insulation.

After steady-state tests the pressure in the model was varied in a cyclic manner (±0.75 bar over a period of about 7 min.) in order to check if pressure cycling could cause significant N_2 transport from the insulation space through the water seal to the steam dome. Tests were performed first with the water lock spray above the water level and later with the spray below the water level. No significant N_2-losses could be measured.

Finally the pressure was increased to BWR-design pressure. Fig. 8 shows the relevant temperature map.

During the test the waterlock level was set at 0.64 m which is somewhat above the spray ring. This caused a local temperature increase (116 and 108 deg. C resp.) on the insulation cover plate near the water lock level, probably due to condensation effects within the gas-filled insulation above the interface. There was no corresponding temperature increase on the liner.

The recorded temperatures in the steam dome are somewhat lower (about 1.5 deg. C) than the actual saturation temperature corresponding to the measured steam dome pressure. This small deviation is systematic for all readings and reflects the effect of limited sensitivity of the automatic data-logger. The sensitivity must necessarily be limited in order to avoid the time-consuming procedure of reading several hundred thermocouples with high accuracy. For engineering purposes this deviation can be neglected.

In general the liner temperature at 85 bar are very similar to the values obtained at 70 bar.

The waterlock performed very satisfactorily during all the gas-filled insulation tests. The level could easily be kept between preset limits during start up and shut down by means of the gas system. During service operation the level was extremely stable.

4.2 Tests with water-filled insulation

After some alterations of the auxiliary system, service tests with completely water-filled insulation were started on 21.5.70. All the existing lining cooling circuits were in operation (60 mm pipe pitch). The water lock spray and insulation gas systems were not used.

The temperature map at 70 bar steam dome pressure (fig. 9) shows lining temperatures in the range between 40 and 75 deg. C. The local temperature peaks at the insulation corner (112 deg. C) were more pronounced than during the gas-filled insulation tests, but the liner was completely free from hot spots.

The heat losses of the insulation were about 20 times larger than experienced during the gas-filled insulation tests. In spite of the relatively high liner heat rates the measured local temperature profile between two adjacent coolant pipes shows temperature variations of max. 12 deg. C.

The temperature map shows further the effect of the previous alterations on the water circulating system. The bottom insulation could be tested at high hot side temperatures with satisfactory results.

The performance of the completely water-filled insulation system at BWR-design pressure is shown on fig. 10. In spite of the extreme thermal conditions the liner temperatures were below 80 deg. C.

As expected the insulation hot spot at the upper edge reached a maximum during this test (154 deg. C). The corner temperature fluctuated somewhat with time indicating the existence of three-dimensional convection currents at the upper edge.

4.3 Test with water-filled insulation and internal gap cooling system

During the earlier tests the heat losses of the thermal insulation were removed by cooling pipes welded to the concrete side of the liner. The Scandinavian cold liner solution, however, also allows for another principle of liner cooling. Cooling water (or gas) can be fed into the bottom of the insulation gap and can be sucked out through penetrations in the top of the insulation gap. The coolant is heated on its way along the thermal insulation from the bottom to the top penetrations and is cooled in an external heat exchanger.

In the model vessel, tests with 'gap cooling' could be performed by connecting the water lock cooling system to six penetrations in the vessel lid. A typical temperature map is shown in fig. 11 at 216 deg. C hot side temperature and approx. 20 bar steam dome pressure. Even during this test a local temperature increase (32 deg. C) at the upper edge of the insulation was seen. As one could expect the local temperature variations on the vertical liner are practically zero, since no heat is transported through the liner. On the other hand there exists an overall axial temperature gradient between the bottom and the top of the vessel, which reflects the increasing temperature of the gap coolant on its way upwards. In order to avoid too high temperature gradients in the model vessel, no tests above 216 deg. C hot side temperature and solely gap cooling were performed. However, gap cooling was tested even at high pressure, when the 20 normal liner cooling circuits were in operation simultaneously but without coolant on the secondary side of their heat exchanger (fig. 12). Thereby a smoothing effect on the vertical temperature gradient of the model vessel could be achieved, since the upper cooling circuits extracted heat from the gap and the lower circuits added the same amount of heat to the lower and colder parts of the gap.

It was concluded from these tests that internal gap cooling practically eliminates local liner temperature variations. However, an internal gap cooling system has to be designed for high flow capacity in order to obtain a low overall vertical temperature gradient in the vessel.

4.4 Tests with high water lock level

These tests were carried out in order to study an insulation system where the insulation in most of the cylindrical part of the vessel is water-filled, while that in the upper part of the cylinder (about 0.5 m in the model) as well as the insulation on the top of the casing are gas-filled. These conditions were obtained by moving the water lock spray upwards in the gap between the insulation and the lining to a position about 30 cm from the upper corner of the casing. As the outlet for the cooling water was still at the bottom corner of the vessel, this set-up could be used for gap-cooling tests with downward flow as well. Tests were started with water circulating through the lining cooling circuits. The pressure was increased in stages to 9, 26, 46 and then to 70 bar. All the lining cooling circuits which belonged to lining parts below the water lock level were shut off in order to study gap cooling downwards. Fig. 13 shows the temperature map at 286 deg. C steam dome temperature, where the cylindrical part of the waterfilled insulation gap is cooled solely by gap cooling downwards. Since gap cooling downwards basically is an unnatural flow direction for water flow of increasing temperature the existence of unstable flow patterns and circumferential temperature variations could be suspected. However, the stable temperature readings obtained, gave no indications of such phenomena.

Fig. 13 shows unusual high cold side temperatures on the upper insulation edge and on the horizontal top insulation. The reason for this is probably that the interface between water and gas within the insulation creates a high partial pressure gradient of steam in the gas-filled layers of the top insulation. This partial steam pressure gradient could cause condensation effects in the colder layers, due to convection currents between hot and cold layers. Similar effects were also observed in gas-filled insulations tests, where the water lock level was set above the water lock spray ring (fig. 8).

5. ACCIDENT SIMULATION TESTS

5.1 Sudden loss of insulation gas pressure

The aim of the experiments was to study the effects of sudden flooding of the gas-filled insulation gap with water near saturation temperature. The model was kept at service conditions with gas-filled insulation for about 1 week in order to obtain steady-state conditions in the lining and the concrete.

The test was initiated by the sudden opening of a valve on a radial penetration leading from the upper part of the insulation gap to the atmosphere. Thereby the insulation gas could be released to the surroundings within a short time and the cylindrical insulation gap was flooded with hot water entraining through the vertical inner annulus of the water lock. The transient was stopped by closing the penetration valve, when the cylindrical insulation gap was filled with hot water. A representative selection of liner thermocouples was continuously recorded during the transient.

This test procedure was repeated several times with increasing rate of flooding. During the fastest test, the vertical gap was flooded within 30 sec. The sudden heating of the liner and the liner cooling circuits during the fastest transient resulted in a simultaneous and unplanned loss of coolant in all the lining cooling systems, since the plastic sections of 9 of the 20 circuits failed. Max. temperatures of about 150 deg. C in parts of the lower half of the lining were recorded during some minutes after the start of the transient. Since the liner cooling system was lost as a heat sink, the model was depressurized and cooled within 30 minutes by blowing steam to the ambient atmosphere. Inspection after lid removal showed that neither the lining nor the insulation had been damaged or deformed during the transient.

The test described above was repeated with the liner cooling system working. All the plastic sections of the lining cooling systems had been replaced by metallic piping. The maximum lining temperature became 125 deg. C for a few minutes.

The above mentioned temperatures are fully acceptable during short transients and remarkably low having in mind the extreme thermal load the insulation system is exposed to, when water of near saturation temperature is flooding the insulation gap. In fact the tested transients were more rapid than the transients after a gas pipe rupture on a large vessel.

5.2 Depressurization tests

These tests were carried out to check if fast pressure transients can have any significant effect on the insulation. It was considered that the most extreme mechanical forces that the insulation would be exposed to would be those arising from the possible formation of steam in the hottest layer of water-filled insulation during a sudden depressurization.

A preliminary series of two tests was performed with one depressurization from 70 to 50 bar and the other from 70 to 20 bar. After the installation of a larger blow-down pipe another series of tests was carried out. The first of these tests was performed with gas-filled insulation: The pressure was reduced from 71 bar to 22.5 bar in 150 s, the steepest gradient being 20 bar in 40 s. The three following tests were with water-filled insulation. During the fastest of these tests, the pressure was reduced from 67 bar to 18 bar in 95 s, the steepest gradient being 6 bar in 5 s. A pressure vs time curve of this test is shown in fig. 14.

Inspection after lid removal revealed that some of the washers under the lowest row of bolts holding down the insulation had rotated very slightly. Otherwise, there was no sign of damage of any kind.

It was concluded from the depressurization tests that the concrete pressure vessel with the Scandinavian cold liner solution imposes no practical limitations on start up and shut down time and on fast pressure and temperature gradients during up-set or emergency conditions.

The fast depressurization tests also demonstrated the capability of the water lock to equalize the pressures between steam dome and insulation gap even during fast pressure gradients.

5.3 Tests with lining cooling system out of function

Gas-filled insulation

An electric power failure at Studsvik was the occasion for an unplanned test with the lining cooling system out of function. The power failure lasted for about 1.5 hours. The vessel was operating at service pressure 70 bar (285 deg. C) at the time. The temperatures of the lining and the water in the water lock increased due to the stoppage of all pumps in the various cooling systems. Temperature readings made just before re-starting the systems after the restoration of power showed that lining temperatures had increased by about 15 deg. C. The highest lining temperature was recorded at the water lock. During the power failure the emergency cooling system for the lining did not need to operate. This system is triggered by lining temperatures of 90 deg. C.

Water-filled insulation in the cylindrical gap

A test simulating stoppage of the lining cooling systems was carried out with service conditions (70 bar) prevailing in the vessel. The insulation was at this occasion not completely water-filled, the uppermost part of the casing insulation being gas-filled. During the first five minutes of cooling system stoppage the temperature of the lining at the water level in the insulation gap rose from 90 to 110 deg. C. Lining temperatures elsewhere were practically constant at 70 - 75 deg. C (water-filled insulation zone).

It should be mentioned that during these tests the water level in the gap was not cooled by a spray as during normal operation.

6. DISCUSSION

The favourable test results during steady state and transient conditions have demonstrated the feasibility of the Scandinavian cold liner solution for gas- and water-filled insulation. Significant for the system are the remarkably low local temperature variations on the liner and the lack of liner hot spots during all the static insulation tests. The free gap between insulation and liner suppresses the propagation of insulation hot spots to the liner. The behaviour of the free gap is explained in the following.

Due to the temperature difference between the insulation cover plates and the liner, turbulent free convection is established in the 'core' of the free gap. The turbulence in the gap mixes the fluent intensively and local temperature variations on the hot side are effectively smoothed within the core of the gap. This effect explains the lack of liner hot spots even in liner regions opposite to pronounced insulation temperature peaks. Local defects in the insulation would thus not have any influence on the integrity of the vessel.

On the cold side of the turbulent gap the intensive mixing of the fluent also tends to minimize local temperature variations on the liner. The approximately uniform heat flux through a certain insulation section is automatically redistributed within the turbulent gap in such a way that the temperature peak on the liner between two coolant pipes becomes minimal. This smoothing effect does not exist when the insulation is directly mounted on the liner, which explains the higher local temperature profiles reported for conventional cold liner solutions. Moreover, in conventional cold liner solutions there always is a liner hot spot at the weld of studs penetrating the thermal insulation. Since the insulation in the Scandinavian solution is mounted on the casing, also this type of liner hot spot is avoided.

The steady-state tests were mostly with gas or water-filled insulation with liner cooling systems in function. The heat losses with water-filled insulation were about 20 times that with gas. However, the absolute values of the thermal losses are of such a small order that both gas and water-filled insulation systems can be considered for use in a reactor vessel.

The vessel was subjected to rigorous transient tests. The accidents that were simulated included the sudden flooding of the gas-filled insulation gap with near-saturation temperature water, rapid depressurization with gas and water-filled insulation, and planned/unplanned loss of the lining cooling systems. The vessel and its insulation have withstood all these tests without any damage.

As mentioned above the insulation concept is characterized by the insulation being mounted on a <u>removable</u> internal casing. This allows for the inspection of both the vessel liner and the insulation itself and also opens the possibility of maintenance or replacement of the insulation. Another important advantage is that the insulation can be erected outside the vessel eventually resulting in a shorter vessel construction time.

A second test series with more extreme accident simulation is being planned for the autumn of 1971.

7. ACKNOWLEDGEMENT

The authors wish to acknowledge the help extended by their colleagues in the various participating organizations in the Scandinavian PCRV Model Project, specially Messrs. Erland Lundkvist and Aage Skinstad from AB Atomenergi.

The cooperation and advice from Messrs. Creussot Loire and the Commissariat à l'Energie Atomique, France, were important for the success of the project.

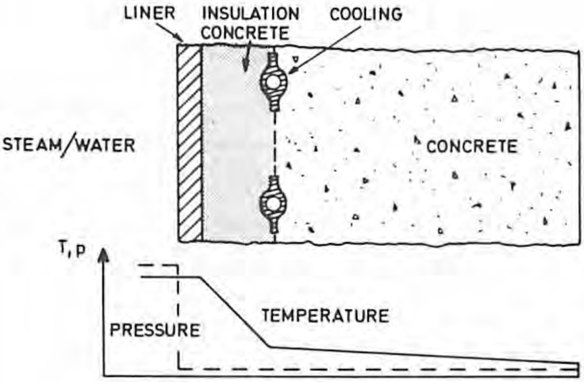


FIG. 1 SOLUTION "HOT LINER"

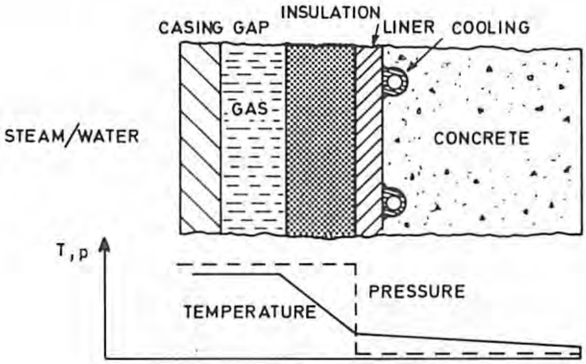


FIG. 2 CONVENTIONAL COLD LINER SOLUTION

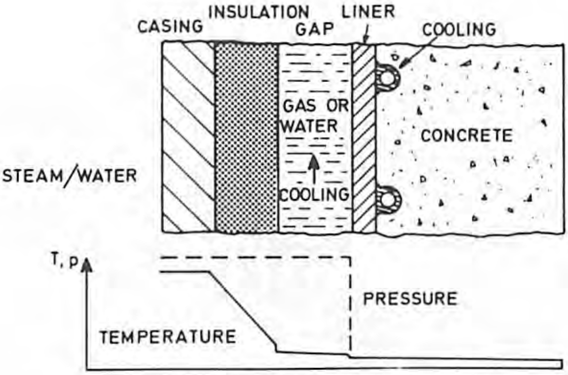


FIG. 3 COLD LINER SOLUTION WITH TURBULENT GAP AND REMOVABLE INSULATION

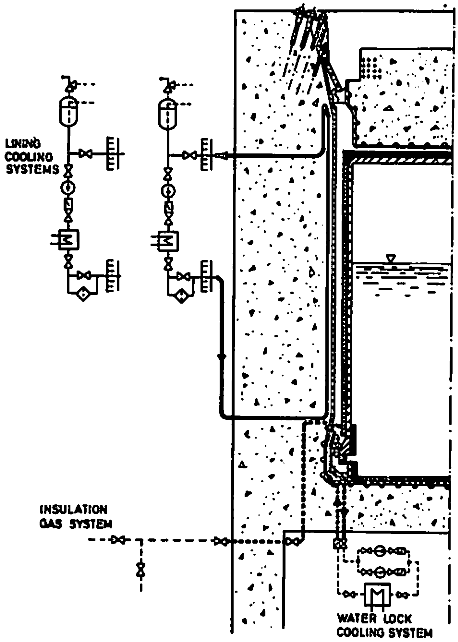


FIG. 4 INSULATION PRINCIPLE,
GAS-FILLED INSULATION

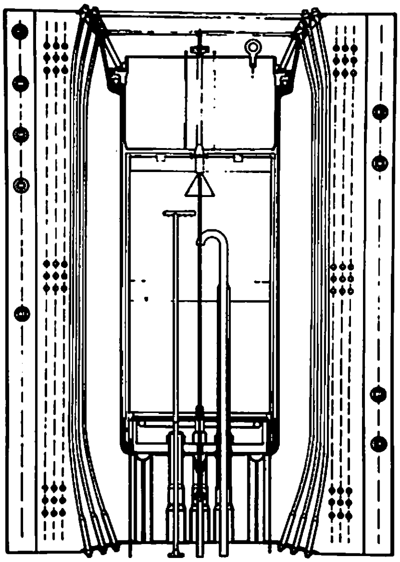


FIG. 5 THE SCANDINAVIAN PCRV MODEL.

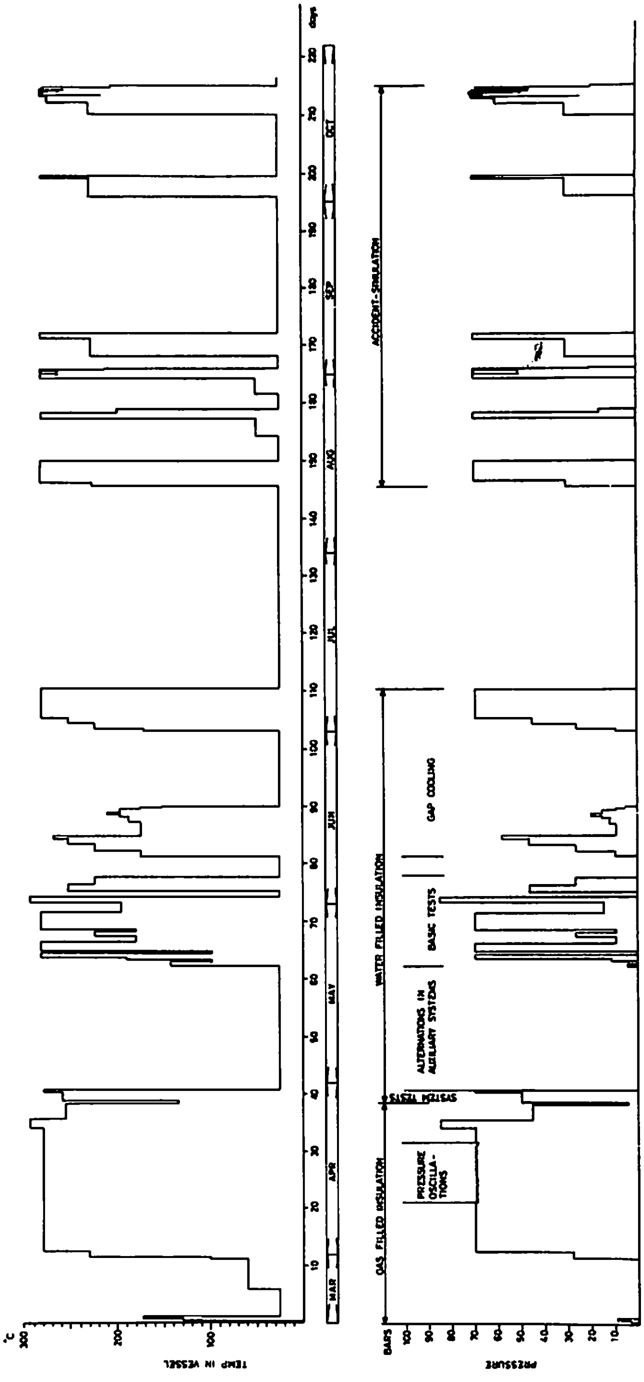
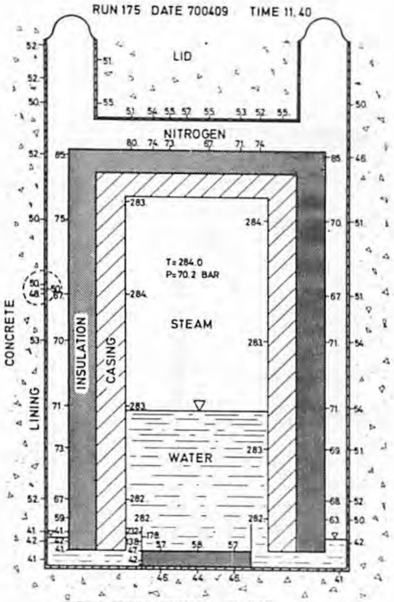


FIG. 8 HISTORY OF INSULATION TESTS



STEAM DOME PRESSURE : 70 BAR
NITROGEN-FILLED INSULATION

FIG. 7 MEASURED TEMPERATURE DISTRIBUTION IN MODEL VESSEL

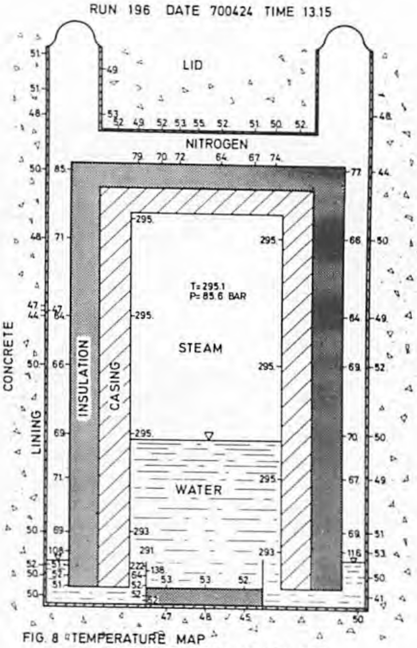


FIG. 8 TEMPERATURE MAP
N_2-FILLED INSULATION AT 85.6 BAR

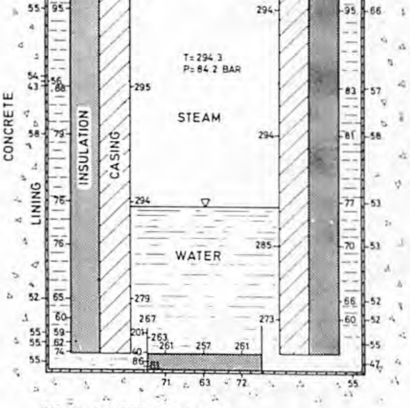


FIG. 10 TEMPERATURE MAP
WATER-FILLED INSULATION AT 84.2 BAR

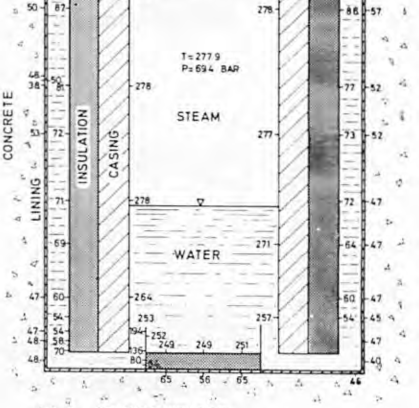


FIG. 9 TEMPERATURE MAP
WATER-FILLED INSULATION AT 69.4 BAR

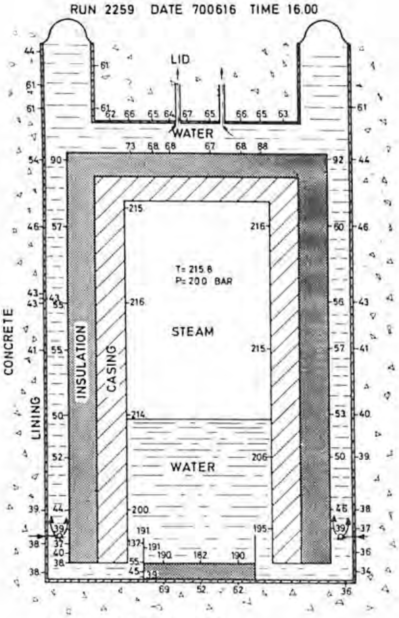


FIG. 11 TEMPERATURE MAP
GAP COOLING UPWARDS
LINING COOLING PUMPS STOPPED

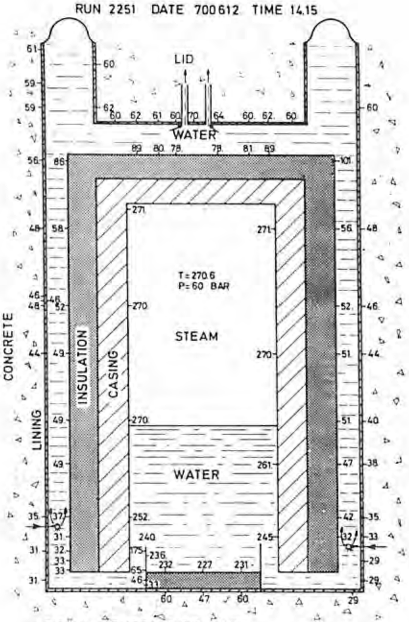


FIG. 12 TEMPERATURE MAP
GAP COOLING UPWARDS
LINING COOLING PUMPS RUNNING

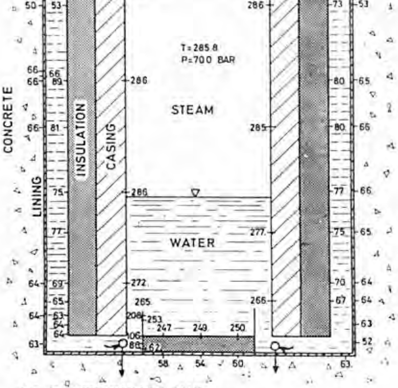


FIG. 13 TEMPERATURE MAP
GAP COOLING DOWNWARDS
GAS FILLED TOP INSULATION

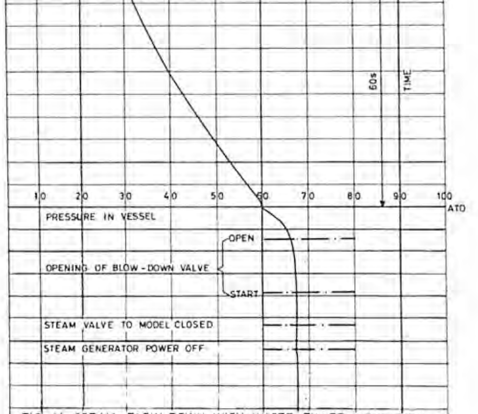


FIG 14 STEAM BLOW-DOWN WITH WATER-FILLED INSULATION

DISCUSSION

Q I. DAVIDSON, U. K.

1. Is the total heat loss acceptable in the case of either gas-filled or water-filled insulation ?
2. Could the failure of any insulation cooling pipe lead to any serious effects on the reactor itself ?

A W. KRAEMER, Sweden

1. Even with water-filled insulation, the heat losses are less than of the order of 1% of the thermal heat output of a 800 MWe BWR.
2. If by "cooling pipe" you mean, for example, a gas pipe penetration, the answer is no. This would not be the most serious accident for the reactor.

Q R. E. D. BURROW, U. K.

The Scandinavian project has been described and studied in relation to a BWR layout. Has any study been made of its applicability to a PWR system ?

A W. KRAEMER, Sweden

No, not in any detail. However, most of the components on the PCRV design for BWR's can also be applied to PWR's.

Q W. O. LIVSEY, U. K.

During the fault case in which the gas-filled annulus became filled with hot water, what concrete temperature was recorded inside the vessel ?

A W. KRAEMER, Sweden

The transients lasted for about 5 minutes. During such a short time the load carrying structure of the PCPV will not change its temperature. The maximum temperature of the liner and the concrete directly in contact with the liner was 150°C.