8.0 POSSIBLE CAUSES

8.1 Statements and Information From Relief Crew

8.1.1 The following information is derived from statements and interviews with employees of Occidental who were not on the installation at the time of the incident. These employees were production operators, maintenance technicians and members of the management team of Piper Alpha.

8.1.2 For the three days before the accident, the installation had been operating on Phase 1 gas production. No written instructions had been issued to the operators on how the plant should be run, but most of the operators employed by Occidental had run the processing plant in this mode before. Operating the system in this mode dated back to 1979 when the gas plant was run in a similar manner, but using a glycol drying system, rather than the methanol drying system which was in use at the time of the accident. Since 1979 the installation had only been operated in Phase 1 on one other occasion: for 60 days during the shutdown of the gas conservation module following an explosion in March 1984.

8.1.3 If the plant had been operating normally - in Phase 2 - and a high level of condensate had occurred in, for example, the demethaniser vessel or the expander receiver, this would have led to a shutdown of the gas conservation system. The reciprocating compressors would trip on a high first stage pressure thus protecting the machines from ingestion of liquids. This primary automatic trip function did not exist for operations in Phase 1 although a single trip function would trip the reciprocating compressors on high liquid levels in the inlet.

8.1.4 When operating the process plant in Phase 2 mode the condensate system normally operated at a pressure of 250 psi. In Phase 1 mode, this pressure was increased to 650 psi. The equipment was designed to operate at this pressure.

8.1.5 On the night shift on Wednesday 6 July, the production management team of the operations superintendent, the deputy operations superintendent and the lead production operator were all temporarily promoted one level above their normal position. It was not unusual on the Piper Alpha installation for persons to be temporarily promoted when someone was not available. It is not at this stage known whether it was usual to have so many people in this situation at one time. The production team consisted of 5 operators, which is the minimum number of persons who can operate the plant.

8.1.6 The production operator working on Phase 1 gas was a contractor who was working on his own and had only arrived on the installation that day.

8.2 Primary Cause of the Accident: Discussion and Preliminary Conclusions

8.2.1 The conclusions set out below are drawn from the information available to the Technical Investigation. The two most probable causes of the accident have been identified, and are described below. However, investigation work continues and further consideration will need to be given to these causes as a more detailed appraisal of the information available is carried out.

8.2.2 The first explosion occurred at about 22.00 hours on 6 July apparently in the gas compression equipment area - Module C.
The main supporting evidence for this is the rapid activation of gas detection alarms at the three centrifugal gas compressors and elsewhere in Module C. (See figure 4.31.)

8.2.3 An explosion in process Module B cannot be discounted since photographs and statements indicate a major hydrocarbon fire in this module very shortly after the explosion was heard. There were however no reports of gas or fire detectors being activated in this module prior to the first explosion.

8.2.4 Captain Morton of the "Maersk Cutter", anchor-handling vessel for MSV Tharos, saw a cloud of grey smoke or dust coming from the east side of the installation in the Module C area immediately after the first explosion.
This evidence, together with that of the gas alarms, leads to the

conclusion that the fire in the process Module B was probably the result of an explosion in the adjacent gas compression Module C. The explosion was no doubt caused by the ignition of a cloud of hydrocarbon gas or vaporised condensate and air in an explosive mixture within the module. A possible source of ignition was the gas turbines driving the centrifugal compressor.

8.2.5 An explosion in Module C would have caused a rapid pressure rise inside the module of sufficient strength to cause severe damage to the fire walls on either side, to the control room wall in Module D, to the fire wall between Modules B and C, and to crude oil process pipework in Module B. Any damaged pipework would have released crude oil under pressure so that within a few minutes a serious oil fire would be burning in Module B, probably centred between the separators and the main oil line export pumps.

8.2.6 The explosion appears to have caused an immediate loss of electrical power. This, together with the strong inference that the diesel powered fire pumps did not start (they had been switched to local 'manual' start for the safety of divers in the water) - meant that there was no water to extinguish the fire or prevent it spreading. There is no evidence to suggest that any attempt was made to start these pumps.

8.2.7 Module B contained a number of pressure vessels and associated pipework containing large volumes of crude oil under pressure (see figure 8.1). Above Modules B and C on the west side, over 1200 barrels of diesel fuel were stored in deck tanks under the floors of the mud module and sack storage areas. Hence the fire that developed in Module B had large amounts of hydrocarbons available to fuel it. It is believed that it was this fire that caused the damage initiating the chain of further fires and explosions. These fires and explosions caused the rupture of the gas pipeline from Tartan at about 2220 hrs and this in turn produced a massive fireball which eventually resulted in the virtual destruction of the installation about 2 hours 45 minutes after the first explosion occurred.

8.3 Possible causes of the Primary Event

8.3.1 **General**

8.3.1. 1 It is not possible to be certain of the cause of the initial explosion. Statements taken from survivors and those on vessels near Piper Alpha tend only to indicate areas where gas leaks or fires were not seen. No-one who was in Modules B or C at the time of the initial explosion has survived.

8.3.1.2 There is no doubt that there was a major disruption to the gas processing system about 10 or 15 minutes before the explosion. This disruption was still causing problems and equipment shutdowns when the explosion occurred and it is considered to be linked, directly or indirectly, with the cause of that explosion.

8.3.1.3 A number of possibilities have been considered which might explain the initial gas leak, explosion and fire and the limited evidence available makes it very difficult for any of these to be dismissed with confidence. It is considered that there are two likely explanations:

Scenario A: A Gas Release from the Condensate Injection Pump 2-G-200A System.

Scenario B: Liquid carry over into the Reciprocating Compressor(s) causing damage and a gas release.

These are described fully below.

8.3.2 **Scenario A: A gas release from the condensate injection pump, 2-G- 200A system.**

8.3.2.1 Condensate from the J-T flash drum was injected into the main oil export line (MOL) by means of the condensate injection system. This is shown in figure 8.2 and comprised two condensate booster pumps and injection pumps together with associated valves and pipework. At least one booster and one injection pump had to be operational to inject condensate from the J-T flash drum into the pipeline. The operating pressures of the system operating in Phase 1 are set in figure 8.2. The booster pumps and injection pumps are electrically driven and operated at 440V and 4. 16kV respectively. Each injection pump was fitted with a pressure relief valve (PSV). The purpose of this PSV was to open at a pre-set pressure, which is in excess of the pump design operating pressure, and return condensate to the condensate suction vessel. This safety device was necessary to ensure that the injection pump did not become subject to excessive over pressures in the event of output restrictions. At the time of the accident, the PSV for the 'A' injection pump had been removed from the system for maintenance and the pump motor was known to be electrically isolated. The 'B' injection pump was in service.

Location of Equipment

8.3.2.2 The J-T flash drum, condensate suction vessel, booster pumps and injection pumps were all located at the 68ft level, as shown in figure 8.3, as were the local control panels for injection pump operation. The PSVs were located in Module C. There was 4 inch diameter pipework running from each injection pump through the floor of Module C to the PSV at a point above the 1-C-116A suction scrubber, situated beside 'A' reciprocating compressor. Isolation valves were fitted downstream of the two PSVs and a common return pipe passed down through Module C floor to the condensate suction vessel.

8.3.2.3 If a release of condensate from the injection pump PSV flange occurred, it would not be seen from the 68ft level.

Isolation of ‘A’ Injection pump on 6 July

8.3.2.4 Sometime during 6 July it had been found that the 'A' injection pump was running "rough" and that the coupling system required maintenance. It was taken out of service and condensate injection into the MOL continued using the 'B' injection pump. A work permit was issued for the isolation of 'A’ injection pump. Normal installation procedures require the maintenance department to initiate the permit to carry out the work: this would probably have been seen and authorised by the production superintendent, the safety department and the control room operator in that order. The electrical department, when requested, would then issue an isolation certificate which would have been attached to the work permit. A red tag which would refer back to the electrical isolation and work permit would have been placed at the point of electrical isolation. In the case of the injection pump the isolation would have been made at the motor starter at the 4.16kV switchboard. A copy of the work permit would have been placed in the rack in the control room.

8.3.2.5 The maintenance department had planned to carry out routine instrument maintenance on the injection pump while the work on the coupling was being done. The production department would normally ensure that the valves necessary to isolate the 'A' pump from the condensate injection process system had been shut.

8.3.2.6 At the time of the accident neither the work on the coupling nor the routine maintenance work had started.

Removal and Setting of Pressure Relief Valves (PSV) on the Installation

8.3.2.7 A contractor, Score UK Ltd, provided labour, equipment and facilities to set PSVs on the installation. Setting involved removing the PSV from service, stripping it down and rebuilding it, testing it, calibrating the setting and installing it back into the system. Two of Score's technicians were on the installation for this work. They operated from their own (Score UK Ltd's) workshop which contained all equipment, tools, spare parts, and technical information for them to do the work. They were issued with a Cold Work Permit for each of the PSVs due for maintenance; the method of work was for Score technicians to liaise with the lead production operator to determine the availability of PSVs for maintenance. When a PSV became available, the relevant Cold Work Permit would be authorised by the maintenance and production supervisors and the Score technician would take the permit to the control room operator. A copy of the permit would be held in the control room and the technician would hold another copy throughout the maintenance work. If the work on a valve was not completed by the time the technician went off shift then the permit was returned to the control room and was "suspended". The technician and the lead production operator would sign the permit at that stage effectively suspending the activity; the document would then be lodged with the safety department until the work was due to commence again.

8.3.2.8 The system of work for the removal of a PSV on the installation was for the Score technician and a production operator to go to the plant and identify the valve. Scaffolding access and rigging equipment would be organised by the production operators for each job. The production operator would isolate the PSV from the process system by closing valves and then remain with the Score technician while a flange of the PSV was cracked open and the residual pressure bled down to zero. The Score technician would remove the valve, fit blank flanges to cover the two open ends of the pipework using the existing bolt and gasket and take the PSV to the workshop for calibration. A supply of blank flanges for this purpose was available in their workshop. When fitted, the blank flanges were not normally pressure tested. They would remain in place until the PSV was ready for re-instatement.

8.3.2.9 During the day shift on 6 July, the PSV on 'A' injection pump (PSV504) was removed by Score technician Rankin. Scaffolding and rigging had been erected for lowering this large valve to the floor in accordance with normal procedures. Rankin obtained a Cold Work Permit for this valve and a production operator isolated the 'A' injection pump from the process system, although which valves were closed is not known. Rankin cracked the PSV flange, removed the valve and took it to his workshop. The other Score technician was left to fit the gaskets and blank flanges to the two open ends of the pipework.

8.3.2.10 Rankin completed the test and calibration on the PSV at around 1800 hrs. He was informed that the crane, required to lift the valve back to Module C, was unlikely to be available that evening, so he returned the Cold Work Permit to the control room where it was "suspended". Rankin’s intention was to re-instate the PSV the next day. Following the normal procedure the Cold Work Permit for this job would have been returned to the safety department via the control room and stored there until the work was to re-commence. The control room log book should have recorded the status of the PSV work.

8.3.2.11 At the shift hand-over at 1800 hours, a reference to the PSV should have appeared in the hand-over notes given by the outgoing lead production operator to the incoming lead production operator. At hand-over, the oncoming shift would be briefed orally by the lead production operator on duties, status of plant, production operations and other relevant matters.

8.3.2.12 Evidence indicates that the production operations team, including the lead operator starting the night shift at 1800hrs on 6 July, were not aware that PSV504 had been removed from 'A' condensate injection pump. Bollands, the control room operator, was certainly not aware of this; neither was Clark, the shift lead maintenance technician, whose job it was to co-ordinate the re-instatement of the electricity supply to the 'A' injection pump motor.

8.3.2.13 The ‘A’ injection pump had an inlet and an outlet suction and discharge valve which were pneumatically actuated spring closure units. They were normally referred to as GOVs (Gas operated valves). On the suction side there was a manual valve upstream of the suction GOV which was normally open. On the discharge side of the pump, there was a non-return valve upstream of the discharge GOV to prevent flow back into pump discharge from the condensate injection line should the pump discharge pressure fall. It would appear that the normal method of isolation, when a pump was taken out of service or for instrument maintenance, was to close the suction and discharge GOVs only. This may have been the valve isolation implemented to remove the PSV on 6 July, except that in addition the manual valve, which was downstream of the PSV in the common return pipe taking condensate that passed through the PSV back to the condensate suction vessel, would have been closed.

8.3.2.14 A more secure method of isolation would be used if the moving parts of the pump were to be worked on. In this case, the instrument air supply to the GOV actuator would be shut-off. If this instrument air supply had been isolated from the GOVs on 6th July, the GOVs could not be opened by operation of push buttons at the local control panel.

Condensate Injection Pump Control and Shut-Down System

8.3.2.15 The starting and running of the condensate injection pump requires a number of conditions to be satisfied. These include booster pump running, suction and discharge GOVs open, operational lubrication and seal oil system, emergency stop button not operated, pump shut-down circuit not operated and PESD not operated.

8.3.2.16 The condensate injection pump could be started and stopped at the local control panel adjacent to the pumps at the 68ft level. Stop buttons were also provided on two other control panels remote from the pump. One of these panels was in Module C, the other at the base of the stairs leading up from the 68ft level. To start a pump it was first necessary to open the GOVs This was done at a local control panel adjacent to the pump by operating the RESET push buttons. This was on a separate panel to that incorporating the start/stop push buttons. The GOV panel displayed the status of each GOV - red for "open" and green for "closed". The display lamps were operated via limit switches on each GOV. Once opened the GOVs would remain open until the motor had started. The GOVs would remain open whilst the pump was running. They would remain open for 30 seconds after the power had been disconnected to allow the pump to come to a standstill before the valves closed.

8.3.2.17 If the pump was isolated, the starter could not provide a start and stop sequence so that once the GOVs had been opened at the local control panel it was impossible to close them from there.

Source of Condensate Release

8.3.2.18 The evidence can support the theory that the initial gas release within Module C was from the pipework associated with the removed PSV504. The location is indicated on figure 8.2. If there was a release then it would have come from the pipework which passed through into Module C from the 'A' injection pump on the 68ft level. The open pipe ends should have had blank flanges fitted to them and there is hearsay evidence to suggest that this was done but it is not known whether gaskets and bolts were correctly fitted.

8.3.2.19 The blank flange on the pump side of the PSV would probably have been subjected to pressure from condensate at 650 psi if the suction GOV had been opened. Following the failure of the 'B' condensate pump, it was the intention of the lead operator, to start 'A' condensate pump. Bollands and Clark have said this and confirmed that no-one on the night shift seemed to have been aware that the PSV for 'A' condensate injection pump had been removed. Nor was Bollands, the control room operator, aware that 'A' condensate injection pump had been electrically isolated. Clark, the lead maintenance technician, was aware that the electrical isolation of the pump was to enable maintenance work to be carried out on the pump itself but not the PSV. When Clark came back to the control room to authorise the work to re-instate the electrical supply for 'A' pump, the permit for the valve removal was not there because it had been lodged with the safety department as a "suspended" permit in accordance with normal practice.

8.3.2.20 Bollands, an experienced operator who had operated the condensate injection system on numerous occasions, thought that either the lead operator or the gas plant operator that night would have had the ‘A’ condensate pump GOVs opened up so that as soon as power became available the pump could be started without delay. Grieve, a production operator who was in the condensate injection pump area at the time of the explosion, believed that he (the lead operator) was lining up the GOVs on both 'A' and 'B' injection pumps. "Lining up" is the term commonly used to mean opening up valves of a system to bring plant into the flow path.

8.3.2.21 Opening the suction GOV would have allowed condensate at suction pressure into the reciprocating pump. The condensate would have passed through the cylinder valves of the stationary pump into the discharge header and from there through the pipework to the blank flange located on the pipe at the position of the removed PSV. If the blank flange had failed to withstand this pressure, a release of condensate would have occurred into Module C. Furthermore, the persons opening the GOVs would not have been aware of a release as they would have been below the module at the 68ft level. They would not have been able to see a release neither would they hear it, as the 68ft level was an area of high noise in which persons normally wore ear defenders. If there had been a release from the PSV pipework it is possible to deduce that the release could not have occurred more than ten minutes before the explosion i.e. the time between the tripping of 'B' pump and the initial explosion. It seems that 'A' condensate pump GOVs would not have been opened until it had been confirmed that 'B' Condensate pump would not restart. This would have to have been some minutes after the initial 'B' Condensate pump trip. If a release did occur, it could have occurred at any time during the 8 1/2 minutes prior to the explosion.

8.3.2.22 It is not possible to give any indication as to the size of the orifice from which such a release would have occurred. It could have ranged from a pin hole if the gasket was leaking, to the diameter of the open pipe if the blank flange blew off.

8.3.2.23 Preliminary work has been carried out by the Health and Safety Executive's Technology Division to assess the explosion effects of a release of flammable gas at the centre of Module C. Preliminary conclusions of this work show that the observed effects in the main control room are indicative of moderate release only and consistent with a flange/gasket failure.

8.3.2.24 The pipe in question was a nominal 4 inch diameter. Other evidence supporting the theory of a release of condensate from this point are the reports from survivors who had been in the mechanical workshop, of "screeching noises" being heard prior to the initial explosion. Gas or condensate escaping from a pipework joint could make such a noise.

8.3.2.25 A release of condensate at the point where PSV504 was located in Module C is entirely consistent with the gas detection zones which indicated gas just prior to the incident.

8.3.2.26 The above theory would be discredited if:

i The blank flanges had been fitted correctly by the Score technician and they had withstood the system pressure without leaking; or

ii The 'A' condensate injection pump suction GOV had not been opened prior to the explosion; or

iii The manual valve upstream of the suction GOV had been closed to isolate the 'A' condensate injection pump and had not been re-opened prior to the explosion.

These points could be verified if the plant in question were recovered from the seabed in reasonable condition.

8.3.3 **Scenario B: Liquid carry-Over Into the Reciprocating Compressor(s) causing damage and a gas release**

General/Process Description

8.3.3. 1 The process arrangement relating to this possible cause of the initial explosion is shown in Figure 4.12. There were two condensate injection pumps, 'A' and 'B', which took the condensate liquid collected in the J-T flash drum, via centrifugal booster pumps 'A' and 'B', and raised its pressure from 670 psi to 1100 psi for injection into the main oil pipeline and export to the Flotta terminal. The condensate pumps and J-T flash drum were all located at the 68 ft level under Module C.

8.3.3.2 The gas in the J-T flash drum was taken from the top of the vessel, and gas not required for well gas lift operations was passed to the flare. Gas required for gas lift purposes passed to the two second stage reciprocating compressors, via suction scrubbers A and B, and was compressed from 635 psi to 1735 psi. The gas was then piped to the gas lift header in Module A and then via individual piping to those oil production wells which required gas lift. The J-T flash drum was filled from two '2 phase' liquid and vapour sources:

i from the condensate suction vessel (2-C-202) see figure 4.12.

ii from gas passed through the first stage of the two reciprocating compressors and throttled by the J-T valve to reduce the pressure from 1465 psi to 635 psi.

8.3.3.3 Under normal operating conditions:

i about 8800 bbl/day of liquid condensate were discharged from the bottom of the J-T flash drum to the condensate pump(s); and

ii about 62 MMSCF/D of gas were discharged from the top of the J-T flash drum. About 12 MMSCF/D passed to the flare, and 50 MMSCF/D to the second stage reciprocating compressors in Module C for compression prior to being used for gas lift at the wells.

Plant Disturbance Prior to the First Explosion and its Possible Effect on the Reciprocating compressors

8.3.3.4 On the evening of 6 July only the 'B' condensate injection pump was in operation, the 'A' pump having been shut down for maintenance that morning. At about 2150 hours the 'B' pump tripped and shut down. The reason for this is unknown. All attempts to re-start the pump failed.

8 3.3. 5 There was therefore no condensate liquid being taken from the bottom of the J-T flash drum although it was continuing to fill with liquids at its normal rate of about 8800 bbl/day. Occidental advise that at this rate the liquid level in the J-T flash drum would rise from its normal level and activate a high level alarm in a little over three minutes. The vessel would be full in a further 12 minutes.

8.3.3.6 The control room operator, Bollands, noticed that two or three minutes after the condensate pump stopped, the condensate alarm panel went off indicating a high level in the J-T flash drum.

8.3.3.7 It is probable that the production operators did not shut down the oil and gas processing system at this stage because a shut down would have resulted in several hours having to be spent trying to get the oil and gas process system operating again. Apparently operators followed normal practice and unloaded the first and second stage reciprocating compressors with a view to reducing the amount of condensate being produced, whilst keeping the plant in operation. This would have resulted in a significant increase in the size of flare.

8.3.3.8 The control room operator, Bollands, was told by the lead production operator, five or ten minutes before the first explosion, that the reciprocating compressors had been 'unloaded'. This is a general term which would normally mean:

i. that the cylinder head end at each of five of the six cylinders on each double-acting reciprocating compressor would have been 'unloaded' pneumatically by the operation of a switch on the compressor control panel - resulting in the suction valves being held open and greatly reducing compressor throughput;

ii. that on the same control panels the two switches which pneumatically opened recycle valves on the first and second stages of each compressor were operated. This recycle valve when open connected the discharge side of the compressor back to the suction side, 'short circuiting' the compressor which would continue to circulate gas without reaching discharge pressure. Each compressor's suction and discharge valves would remain open unless the compressor was switched off or was tripped out by its protective system.

8.3.3.9 It may be assumed that the recycle valves were also opened when the reciprocating compressors were unloaded, but this cannot be confirmed.

8.3.3.10 A few minutes before the initial explosion, production operator Grieve had looked at a gauge and noted that the level in the J-T flash drum was higher than normal.

8.3.3. 11 A few minutes before the initial explosion two centrifugal compressors shut down, possibly due to pressure surges resulting from the unloading of the two reciprocating compressors. Seconds before the initial explosion, the control room operator became aware that the third centrifugal compressor had shut down. About half of the normal flow of liquids entering the J-T flash drum would originate from the discharge scrubbers of the three centrifugal compressors, so that even though the reciprocating compressors were unloaded, the J-T flash drum was continuing to fill.

8.3.3.12 It is possible that in the remaining minutes after the high level was noted by production operator Grieve, the J-T flash drum filled and condensate liquid carried over into the gas outlet pipework and thence to the much smaller second stage reciprocating compressor suction scrubbers. These small vessels would fill with liquid in one to two minutes and the liquid would then be drawn into the reciprocating compressors.

8.3.3.13 The reciprocating compressors were designed to handle only gas and the system was designed to ensure that any entrained liquids would be removed before gas entered the compressors. If liquids entered the cylinders of the compressors, they would have caused sufficient shock loadings in passing through them and the recycle system to cause the compressors, or associated pipework, serious damage leading to a major gas leak. The prevailing wind would have blown any gas towards the east end of Module C. Gas was detected in this area shortly before the initial explosion.

8.3.3.14 Any gas cloud in the eastern half of the module could have been ignited by the hot casing of a centrifugal compressor's gas turbine or by frictional sparks from a damaged reciprocating compressor or compressors. A failure of a reciprocating compressor could result in its disintegration and projectiles from it (eg cylinders and cylinder heads) causing damage to the fire wall and to the oil process pipework or vessels in Module B.

8.3.3.15 This theory is supported by the following:-

i The time (approximately 15 minutes) from the shutdown of the condensate injection pump to the initial explosion coincides closely with Occidental's estimate of the time for the J-T flash drum to fill and overflow.

ii Debris were seen travelling over the sea some 400 metres north west of the installation after the initial explosion by Carson, the second engineer of the MV Silver Pitt.

iii The overhaul of the 'A' and 'B' reciprocating compressors in February 1988 and May 1988 revealed that seven of 16 studs were broken on the No 1 cylinder yoke to stuffing box flange on the 'A' compressor, and five of 16 studs were broken in the same place on No 3 cylinder on the 'B' compressor. These studs were all replaced. Those on the remaining five cylinders of each compressor were torque tested to ensure that they were not broken. The investigation carried out for Occidental by Offshore Inspection Services revealed that the cause of the stud failure was fatigue cracking due to cyclic stresses from compressor operation. It is possible that fatigue cracks were present in some of the studs holding the remaining cylinders' yokes to stuffing box flanges together. Shock loadings resulting from the ingestion of liquid into the compressor cylinders could have caused fatigue cracks in these studs to propagate, leading to the separation of one or more cylinder yokes to stuffing box flange joints and hence destruction of the compressor.

iv Some survivors reported hearing a high pitched scream, or metal-to-metal noise, or sharp crack, immediately before the initial explosion. This could have been the failure of one of the compressors.

v Bollands and Clark noted that gas was detected in Module C.

Point (iii) above might be verified if the reciprocating compressors are recovered.

8.3.3.16 The above theory would be discredited if:-

i The J-T flash drum was not completely filled with condensate liquid before the explosion occurred.

ii The reciprocating compressor concerned shut down due to the high liquid level in the suction scrubber.

iii An unloaded reciprocating compressor could withstand the ingestion of liquid without damage. This question has been put to the manufacturers. A response has still to be received.

iv Liquid carry over from the J-T flash drum was passed to the flare, via differential pressure control valve DPCV 723, rather than entering the unloaded compressors.

Preferred Theory

8.3.4.1 Whilst neither theory can be discredited, the present evidence more clearly supports the first.

[Excerpt from Chapter 10]

10.0 PRELIMINARY CONCLUSIONS

10.1.1 The most probable cause of the initial explosion is thought to have been a release and ignition of gas (condensate vapour) from a section of pipework in Module C, following an earlier process disturbance. The condensate was probably released from the site of a pressure relief valve (PSV) which had been removed from pipework associated with the isolated condensate injection pump 'A'. It is probable that this pipework was inadvertently pressurised whilst operators were dealing with a plant disturbance. The operators were probably unaware that the PSV had been removed.

ACKNOWLEDGEMENTS

In investigating the circumstances that led to the Piper Alpha accident, I received any offers of assistance from both organisations and individuals. For all of these offers I extend my thanks. In addition, I wish to record my gratitude for the assistance provided to me, often at very short notice, by the Health and Safety Executive in providing both Inspectors and technical experts, the Department of Transport Marine Directorate, Lloyd's Register of Shipping, the Coastguard Service and the Grampian Police. Also, both the Procurator Fiscal in Aberdeen and the installation operator, Occidental Petroleum (Caledonia) Ltd. have given unstinted co-operation to my Investigation.

Particular thanks are due to those survivors of the disaster who, without exception, gave, to my Inspectors detailed accounts of their harrowing experiences, to Mr Ole Andersen who made his remarkable video of the accident available to the Investigation, and to other observers, Mr Miller in particular, who contributed their photographs. Photographs taken from these sources illustrate this Report.

I also wish to record my admiration for the skill and courage of the emergency services and other involved in the rescue operation, evidenced in so many accounts of the disaster.

Finally I would like to thank all Inspectors, both my own and from the Health and Safety Executive, and my other staff who have worked extremely hard and under great pressure to make possible this interim report.