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**AUSTRALIAN ATOMIC ENERGY COMMISSION  
RESEARCH ESTABLISHMENT  
LUCAS HEIGHTS**

**ACOUSTIC EMISSION MONITORING OF A STEAM  
RECEIVER PRESSURISED TO FAILURE**

by

**K. BROWN  
R. HARRIS  
B. WOOD**

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ABSTRACT

The Australian Atomic Energy Commission and the Australian Welding Research Association have conducted acoustic emission monitoring of a large defective pressure vessel during pressurisation to failure. Using acoustic emission source location equipment, it was possible to locate, in real time, areas of high activity. Later, fractographic examination of the failed vessel indicated that failure had initiated at the area of highest activity and this area was identified well before failure occurred.

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ACOUSTIC; EMISSION TESTING; PRESSURE VESSELS; FAILURES

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## 1. INTRODUCTION

A pressure vessel, used as a steam receiver at the Morwell power station of the State Electricity Commission of Victoria (SECV), was taken out of service owing to defects in the nozzle welds. It was later donated to the Australian Welding Research Association (AWRA) for experimental tests; these commenced in 1973.

The pressure vessel was made in England from forged Cr-Mo steel. The 3.65 m long cylindrical body was 60 mm thick and penetrated by five nozzles which were placed three on one side and two on the other; the nozzles were fabricated in Australia. In service these nozzles were connected to external pipework but, for the test program, they were blanked off by welded plates. An access port was already present in one of the hemispherical ends. Figure 1 is a drawing of the vessel and Figure 2 is a fisheye photograph of the vessel in the testing bunker.

The vessel was in service for approximately ten years and was operated at a nominal pressure of 9.6 MPa (1400 psi) at 550°C. The defects causing its removal from service were extensive cracks in the vessel adjacent to all nozzle reinforcements. These cracks ran circumferentially around the nozzle penetration, and those on the inside surface of the vessel were up to 25 mm deep.

The intention of the experimental program was to pressurise the vessel to failure after many pressure cycles designed to accelerate the growth of the flaws in the nozzles by cyclic fatigue. Numerous pressurisations were carried out at progressively increasing pressures, including a group of 995 cycles in the range 6.9 to 24.1 MPa.

## 2. ACOUSTIC EMISSION MONITORING

The project involved several organisations each of which considered a specific aspect of the experiment, *e.g.* stress analysis, strain gauging, ultrasonic testing and dye penetrant flaw monitoring. The Australian Atomic Energy Commission undertook the acoustic emission (AE) monitoring of the vessel during pressurisation. The results of earlier AE monitoring experiments were reported by Woodward *et al.* [1976].

The AE monitoring experiments were designed to gain experience in the use of such a technique as a non-destructive testing tool. The principle of these techniques is that when a stress, which causes the production or motion of submicroscopic defects, is applied to a structure, energy is released as transient elastic waves

that propagate through the structure. These bursts of acoustic energy may be received at a transducer remote from the source. If a triangulation technique is used, the spatial location of each event can be determined, and it is possible to identify localised areas of high AE activity. The stress concentration effect of flaws can induce local yielding with associated acoustic emission which may be used to locate the flaws at stresses below the general yield. Localised areas of high activity can be investigated by other non-destructive testing techniques to establish whether a flaw was responsible for the high activity.

When using AE techniques, it must be recognised that, in general, emission will be produced only when the test stress or pressure exceeds any previous value; this memory phenomenon is known as the Kaiser effect [Kaiser 1950]. A further problem is that some materials which deform primarily by a ductile process may produce little burst-like emission [Birchon 1976]. In particular, many clean high-quality steels, similar to those used for fabricating the AWRA pressure vessel, are relatively quiet (in an AE sense) and will produce useful emission only during yielding. After yielding, the material may flow plastically with very little AE; this is shown in the data of Figure 3, which represents the acoustic emission during the tensile testing of a sample of a similar Cr-Mo steel.

### 3. MONITORING METHODS

The AE data were initially monitored by recording seven tracks of information from piezo-electric transducers attached to different parts of the vessel, and then laboriously analysing the data at a later time to calculate the areas on the vessel from which AE pulses originated [Woodward *et al.* 1976]. For the final pressurisation cycles discussed in the present work, a special purpose analogue computer (FLIC 3) was purchased from the Southwest Research Institute (USA). This unit allowed on-line determination of the location of sources of AE events which might be associated with the presence of an active defect.

The vessel was pressurised, using an air-hydro pump, in a bunker at the Snowy Mountains Engineering Corporation premises in Cooma, NSW. The final stages of the pressurisation were carried out at a vessel temperature of 14°C. For these final pressurisations, three sensors comprising a magnet hold-down unit, a steel waveguide, and a piezo-electric transducer at the end of the waveguide provided signals for the

FLIC unit to give the spatial map of AE activity. The positions of these are shown in Figure 4. Specifically the geometric arrangement of the sensors was designed to monitor nozzle 2, as ultrasonic testing conducted after early pressure cycles indicated that some growth of existing cracks had occurred adjacent to this nozzle [Woodward *et al.* 1976]. However, the area monitored was significantly larger (approximately 1.0 x 1.5 metres) and included portion of nozzle 3.

Three Dunegan AE transducers and three accelerometers were attached to other parts of the vessel. The signals from the three waveguide units went directly to the FLIC computer, and the other signals were fed to an instrumentation tape recorder. The signal from one of the Dunegan units was fed into an r.m.s. voltmeter and then to one pen of a two-pen chart recorder. This signal gave some idea of the burst rate for the total AE activity in the vessel. An analogue signal proportional to the cumulative count for a specified rectangular area on the FLIC spatial map was fed to the other pen of the chart recorder. The signal from one of the accelerometers was used to provide an audible indication of the total AE activity.

The inside of the bunker was monitored using a television camera with a fisheye lens to obtain a wide angle of view, and another camera monitored the display of the FLIC unit. The two video signals were combined to form an image similar to that shown in Figure 5, and recorded on video tape. A schematic diagram of the instrumentation is given in Figure 6.

#### 4. EXPERIMENTAL RESULTS AND DISCUSSION

The time history of the final four cycles is given in Figure 7. As the pressurising pump was near the limit of its performance, there were breaks in the program to allow pump repairs to be carried out. A great deal of AE in the vessel was evident during all pressurisation cycles, but much more arose from such phenomena as the motion of the vessel on its supports and the bedding of the manhole cover on its seal. Much of this activity produced artefacts within the monitored triangular area. Artefacts are apparent activity within the monitored area which result from AE events which are well outside the area. Most artefacts are easily recognised as they appear as straight lines emanating from the centroid of the triangle defined by the FLIC sensors. Figure 8 is an annotated reproduction of the FLIC display, and the artefacts are indicated.

After the pressure had exceeded approximately 56.5 MPa (8200 psi), the artefact activity diminished greatly, presumably because the vessel had settled on its supports and the manhole cover had bedded in completely. Strain gauges on parts of the vessel away from both the nozzles and the vessel ends indicated hoop plastic strain after the previous test pressure was exceeded. This plasticity was monitored up to the useful limits of the strain gauges (approximately 4000 microstrain).

The AE activity in the region monitored by the FLIC unit, showed a distinguishable pattern of events (Figure 8). Nozzle 2 gave copious amounts of AE distributed generally around the nozzle penetration. This activity outlined the position of the nozzle reinforcement on the FLIC screen; however, the image was distorted owing to the interference of the hole made in the vessel shell by the nozzle. This hole blocked the direct sound paths from sources on the side of the nozzle opposite any one of the location transducers. A large amount of AE was observed at a very localised position on the underside of nozzle 3 and only just within the monitored area. At this stage, the emission detected within the area monitored by the FLIC unit comprised the majority of the emission detected from the entire vessel.

In the later stages of the final pressurisation, the AE activity finally decreased, possibly because of reduced pumping rate (Figure 9); however, the relative proportion of the activity at the nozzle 3 location tended to increase and become more localised. A quantitative picture of the distribution of AE activity between nozzles 2 and 3, as seen by FLIC, is given in Figure 10. The activity at nozzle 3 suggested a higher strain concentration and therefore implied that this position was the most likely initiation point for the final fracture of the vessel. The vessel finally failed at 62.1 MPa (9000 psi) with no increase in AE activity before failure. The lack of an AE warning of imminent failure is typical of materials behaving in a ductile manner [Birchon 1976; and also see Figure 3].

When the top of the bunker was removed, the nature of the catastrophic failure was clearly evident (Figure 11). A graphical reconstruction of the vessel fragments, carried out by Mr. S Ambrose of AWRA, is reproduced in Figure 12. The failure was almost entirely brittle in character and appeared to result from localised exhaustion of ductility, with no apparent involvement of any significant pre-existing defect.

The fractography of the broken surface of the fragments suggested a number of possible sites for the origin of the initial fracture. A group of experts (members of AWRA Project Panel 1) concluded, from a fractographic examination, that a location under nozzle 3 was the primary initiation point. This point was coincident with the area of highest AE activity during the later stages of pressurisation.

The failure appeared to propagate axially along the vessel from this point, then to branch circumferentially between the nozzles. Nozzles 2, 3 and 4 then lifted and separated, causing an axial fracture diametrically opposite the underside of these nozzles. This fracture acted as a hinge which allowed the three nozzles to lift. The only evidence of ductile fracture was in a narrow shear lip adjacent to the external surface of the vessel and along this 'hinge'.

The absence of a flaw at the point of initiation was somewhat surprising; however, the highly localised acoustic activity and subsequent failure may have resulted from a steep strain gradient adjacent to the reinforced and highly restrained nozzle penetration. The failure of the pre-existing cracks to propagate confirms predictions of stress analysis that they were not located in highly stressed regions during simple pressurisation. Their formation during service undoubtedly resulted from loadings imposed by external supports and pipework, rather than from internal pressure.

The conditions encountered in this test are clearly different to those that would exist in a non-destructive proof test. The vessel suffered extensive plastic deformation at pressures considerably higher than any conceivable proof test pressure. Also, the failure occurred by the local exhaustion of ductility in a highly restrained region, rather than by the initiation of yielding in a highly stressed region. However, the ability of the equipment to find localised acoustic emission sources was clearly demonstrated, and it is most likely that it would work successfully in a non-destructive proof test.

It should be cautioned that, in this study, a large flaw may have escaped detection if it caused failure at a low pressure when artefact activity was high. For similar tests it is clear that more care is needed in the provision of silent supports and the seating of flanges and access ports.

## 5. CONCLUSIONS

Acoustic emission signals located a position on the vessel as the possible primary initiation point for final failure several hours before the event and at approximately 90-95 per cent of the failure pressure. This prediction was verified by a later examination of the vessel fragments.

Although acoustic emission techniques were able to locate the point at which failure would initiate, they gave no useful warning of imminent failure because of the ductile nature of the material.

Although this was a deliberate test to destruction, it is believed that the results indicate that acoustic emission techniques could be used successfully as a non-destructive testing tool on similar vessels.

## 6. ACKNOWLEDGEMENTS

A great many people were involved in the pressure vessel investigations, however, special thanks are due to the Australian Welding Research Association for inviting our participation; the staff of the Snowy Mountains Engineering Corporation, specifically John Wade, Ian Rees and Geoff Thompson, and the project coordinator, Mr Stan Ambrose of AWRA, who allowed us to use his graphical reconstruction of the vessel.

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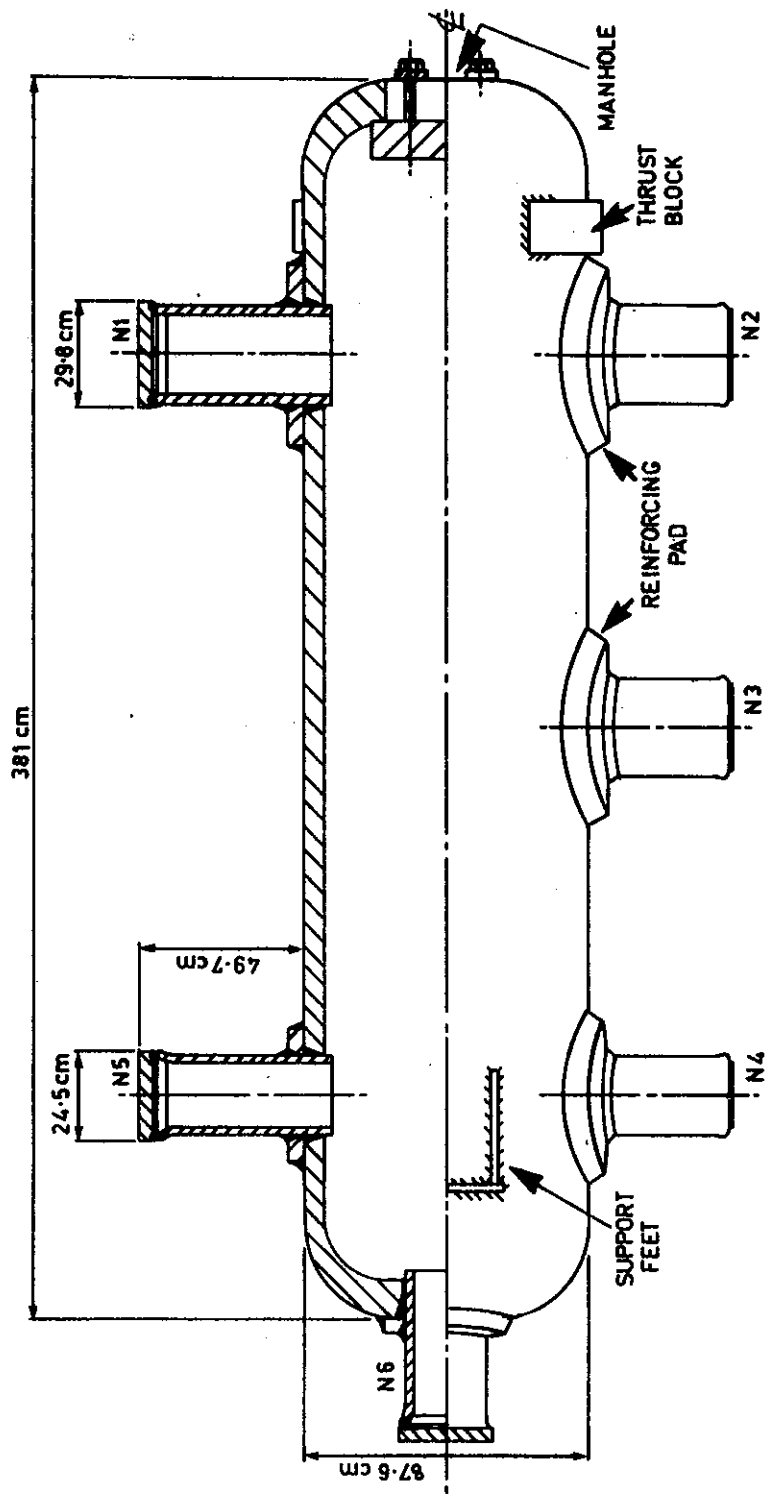


Figure 1 Drawing of pressure vessel

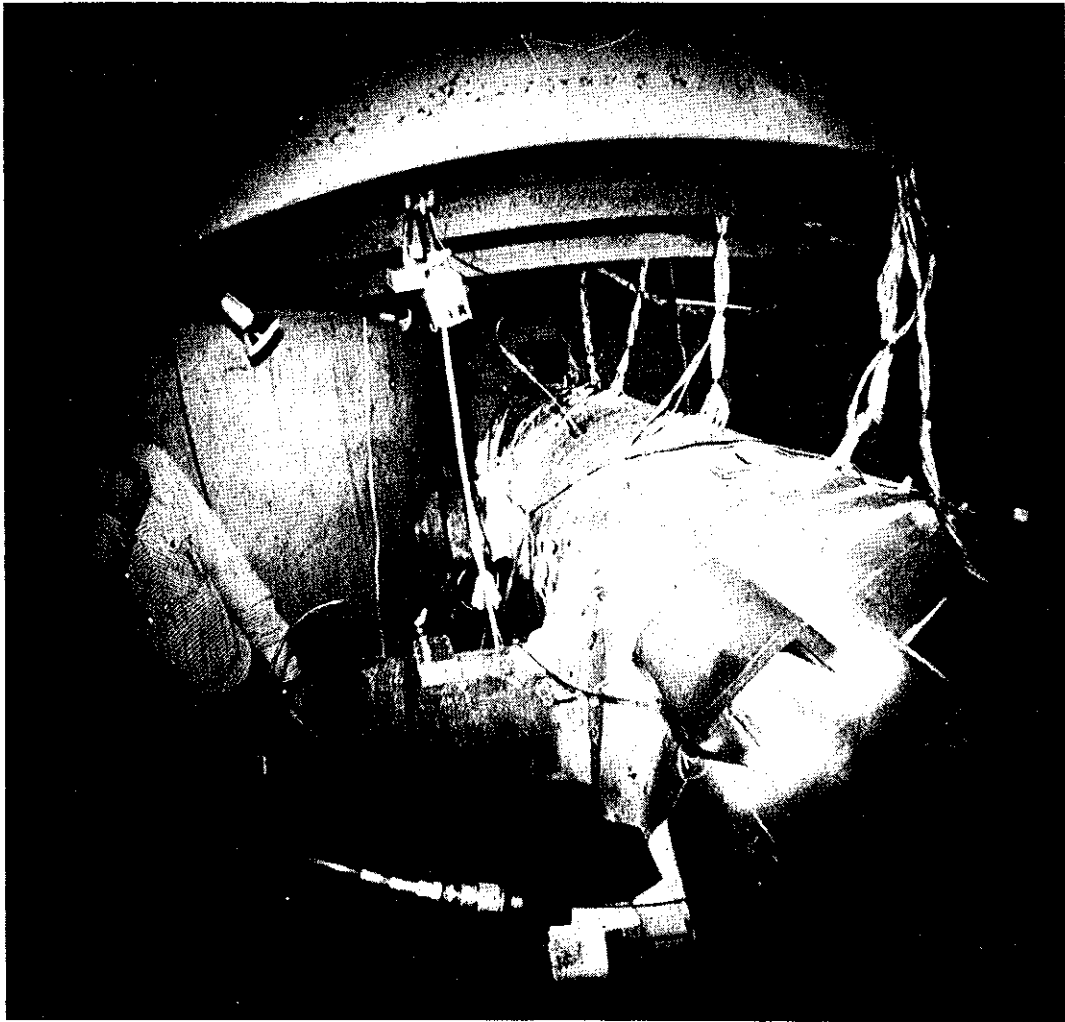


Figure 2 Photograph of the vessel in the bunker. (The apparent distortion results from the use of a fisheye lens. The person's left hand is close to nozzle 2. Nozzles 3 and 4 can be seen further from the camera.)

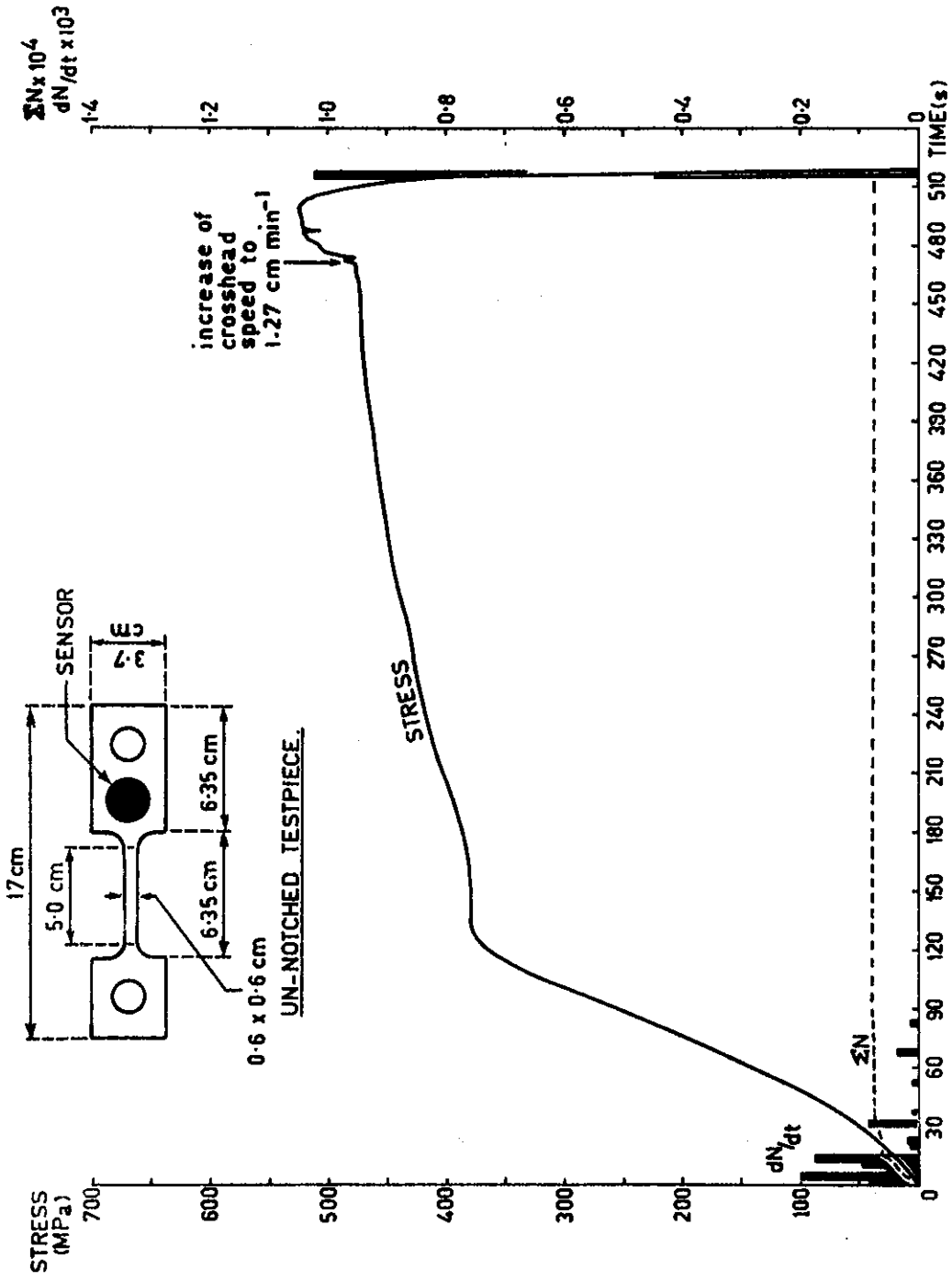


Figure 3 Acoustic emission behaviour of a tensile test sample of steel similar to that used in the vessel. (Note that most activity occurs during yielding.)

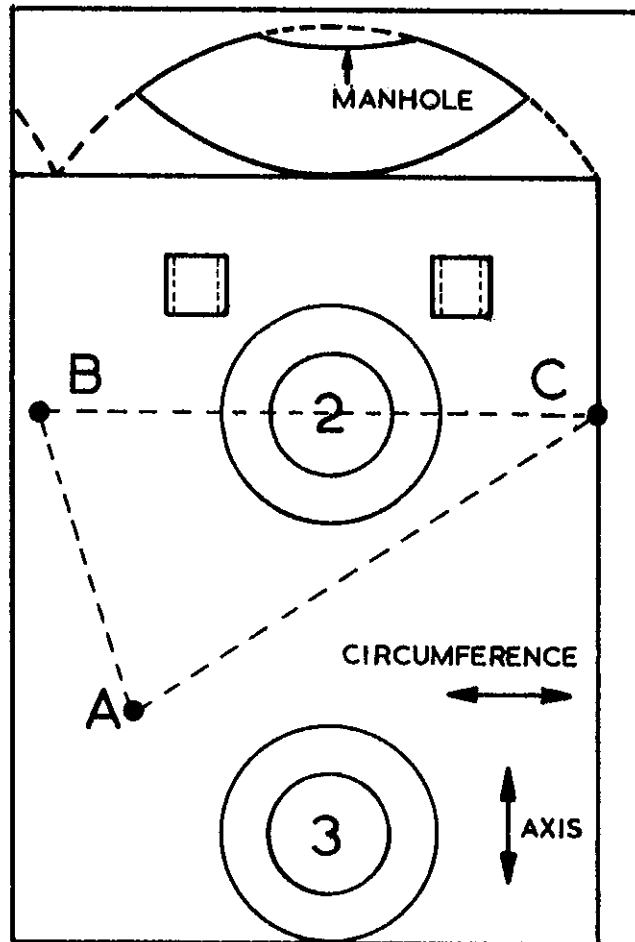


Figure 4 Positioning of the transducers used for source location.  
(These are in the vicinity of nozzles 2 and 3. The transducers are identified A, B and C.)

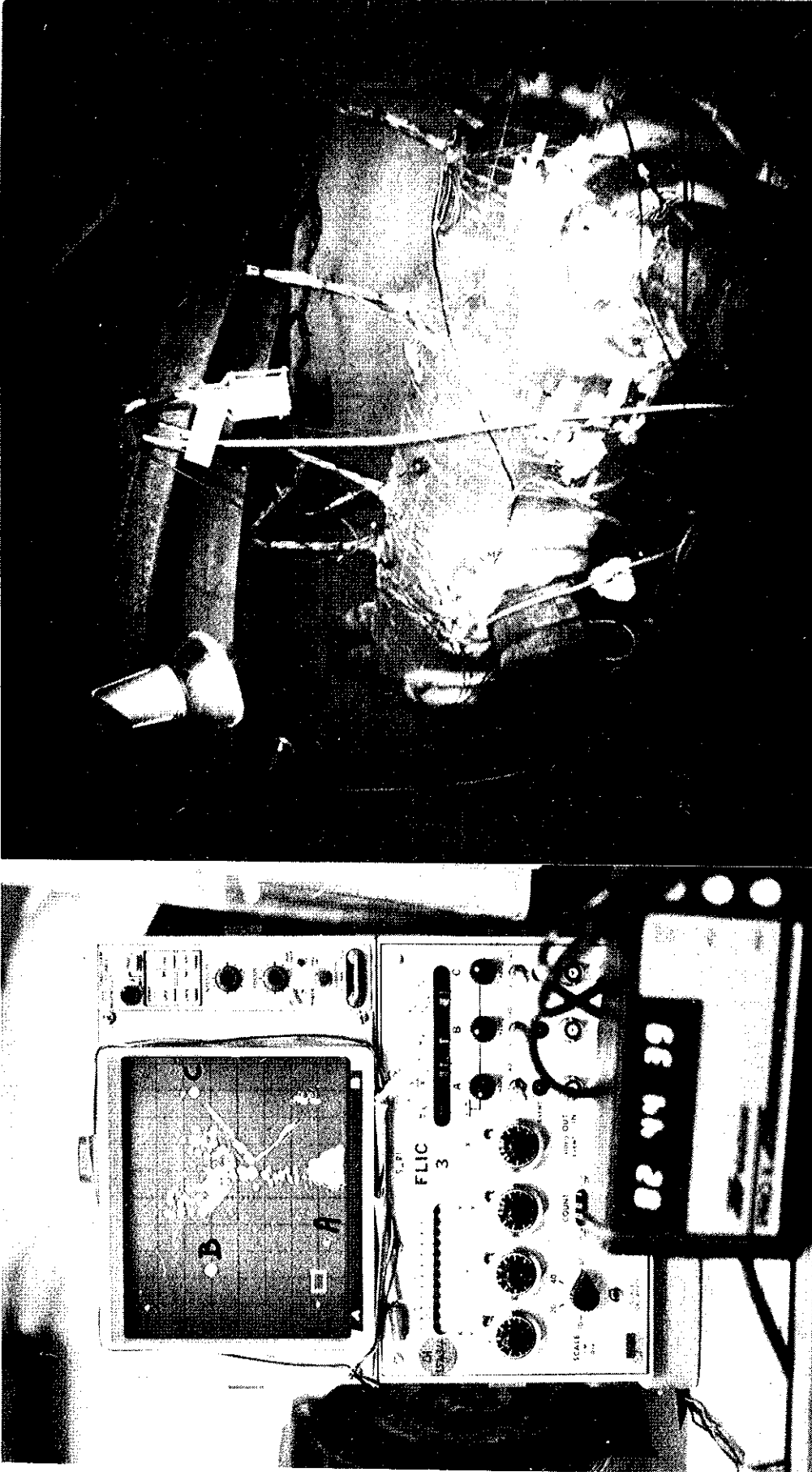


Figure 5 Typical composite video picture. (The transducer positions have been identified on the screens of FLIC and are as shown in Figure 4. The reinforcement of nozzle 2 has been delineated by acoustic activity and a high proportion of emission sources is evident adjacent to nozzle 3.)

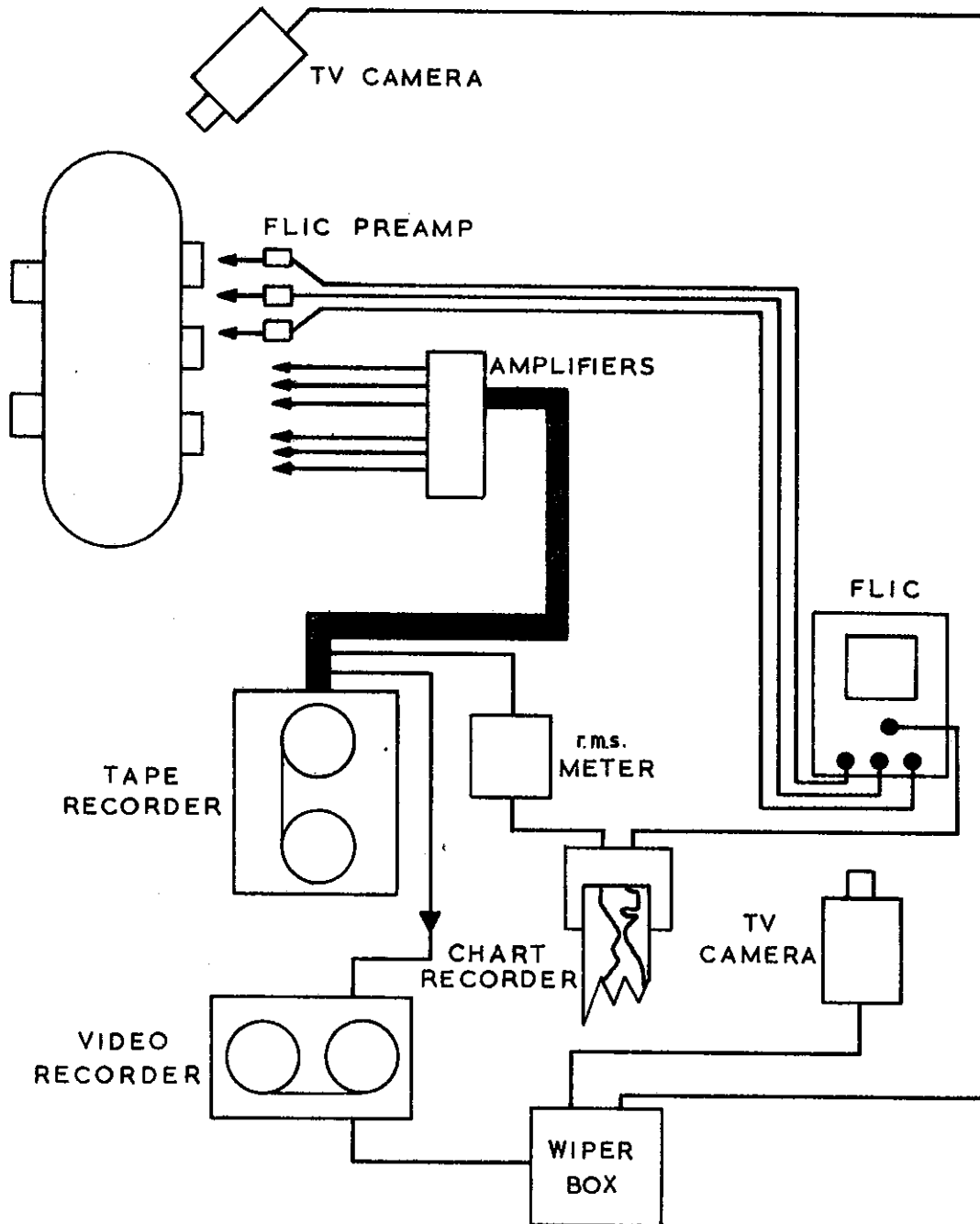


Figure 6 Schematic of instrumentation

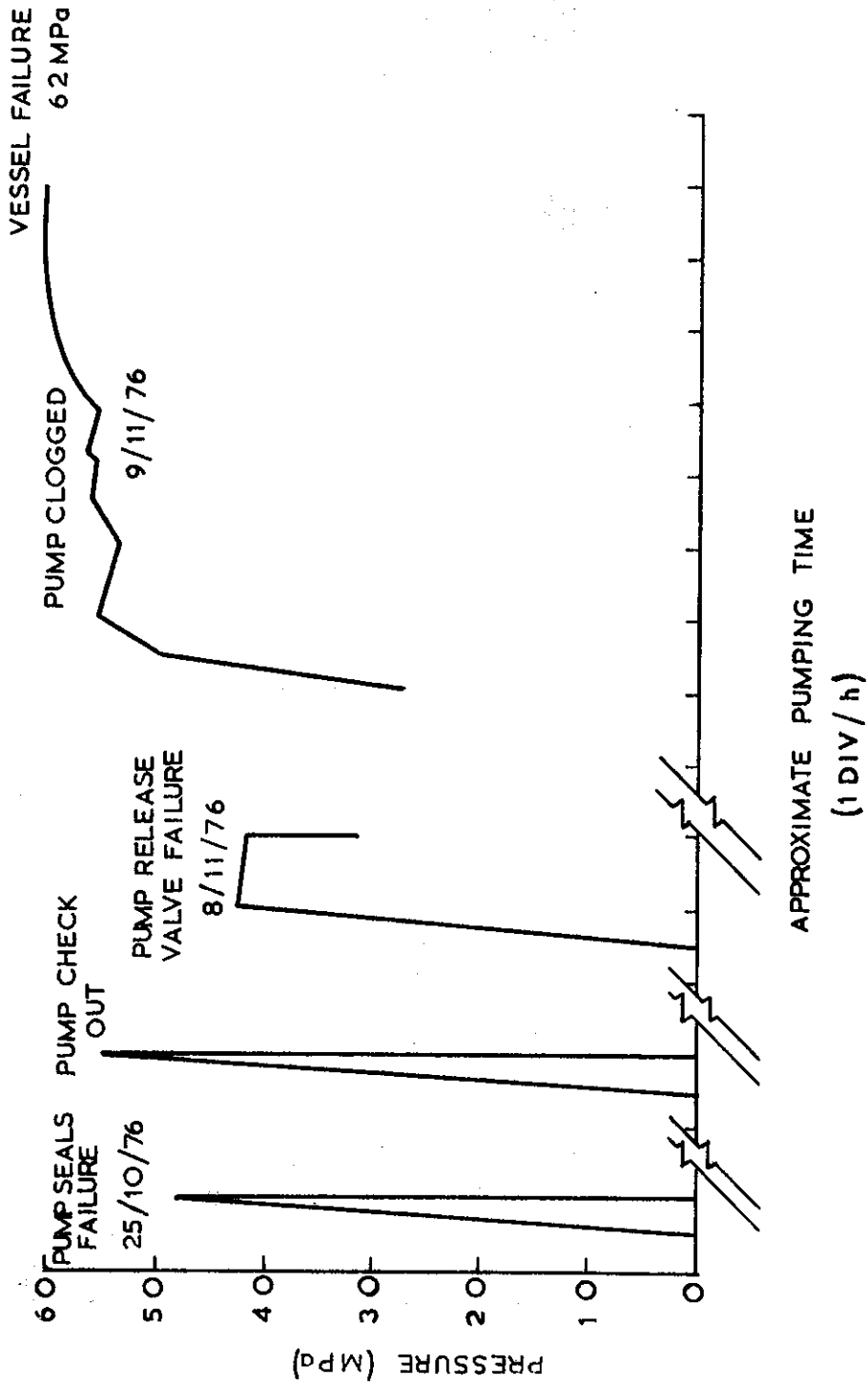


Figure 7 Time history of final pressurisation cycles.

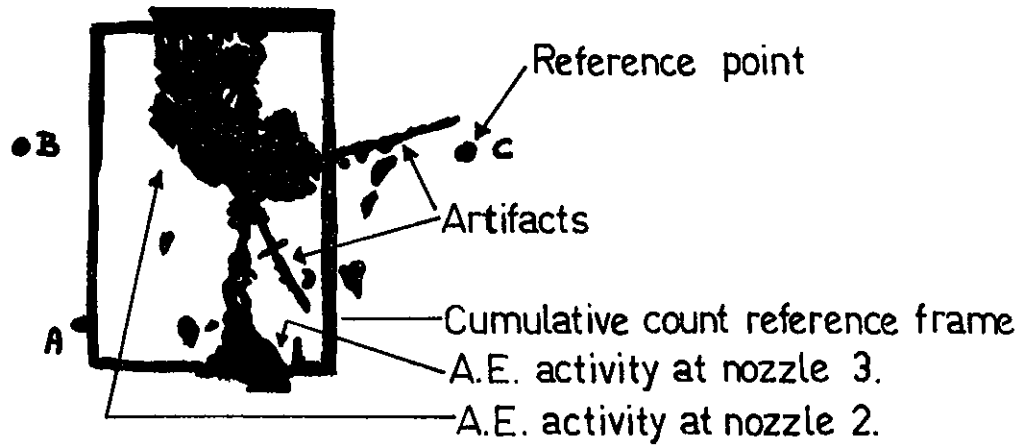


Figure 8 Annotated reproduction of FLIC display. (The geometry is the same as that in Figure 4.)

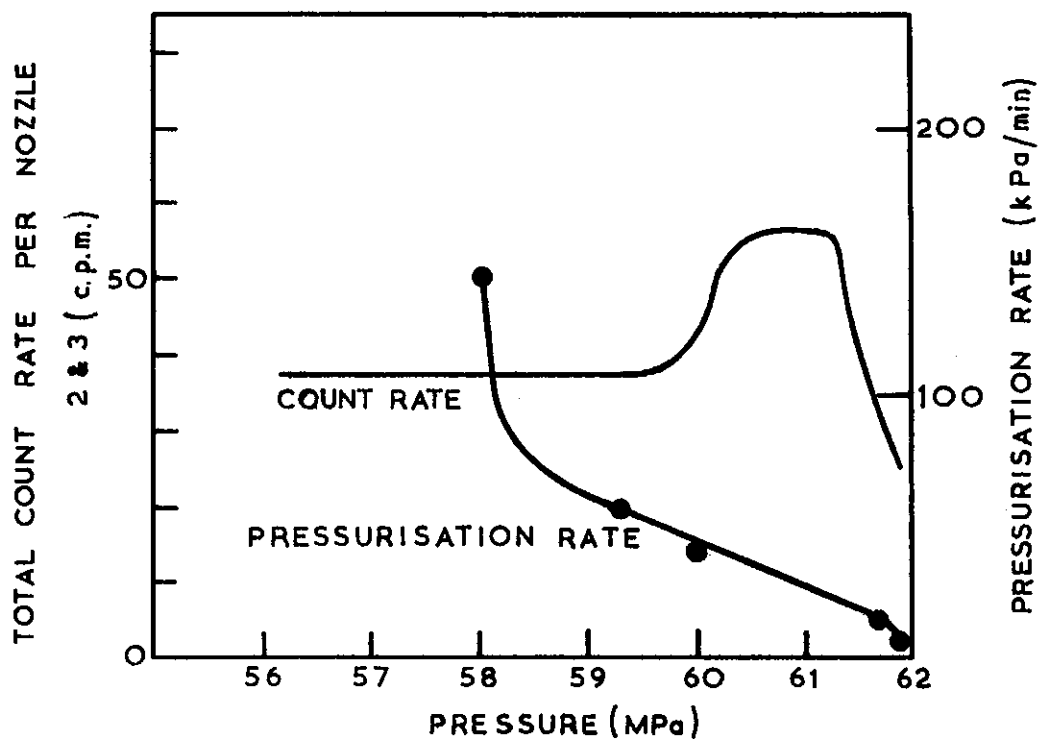


Figure 9 Acoustic emission and pumping rate history during the final stages of pressurisation.

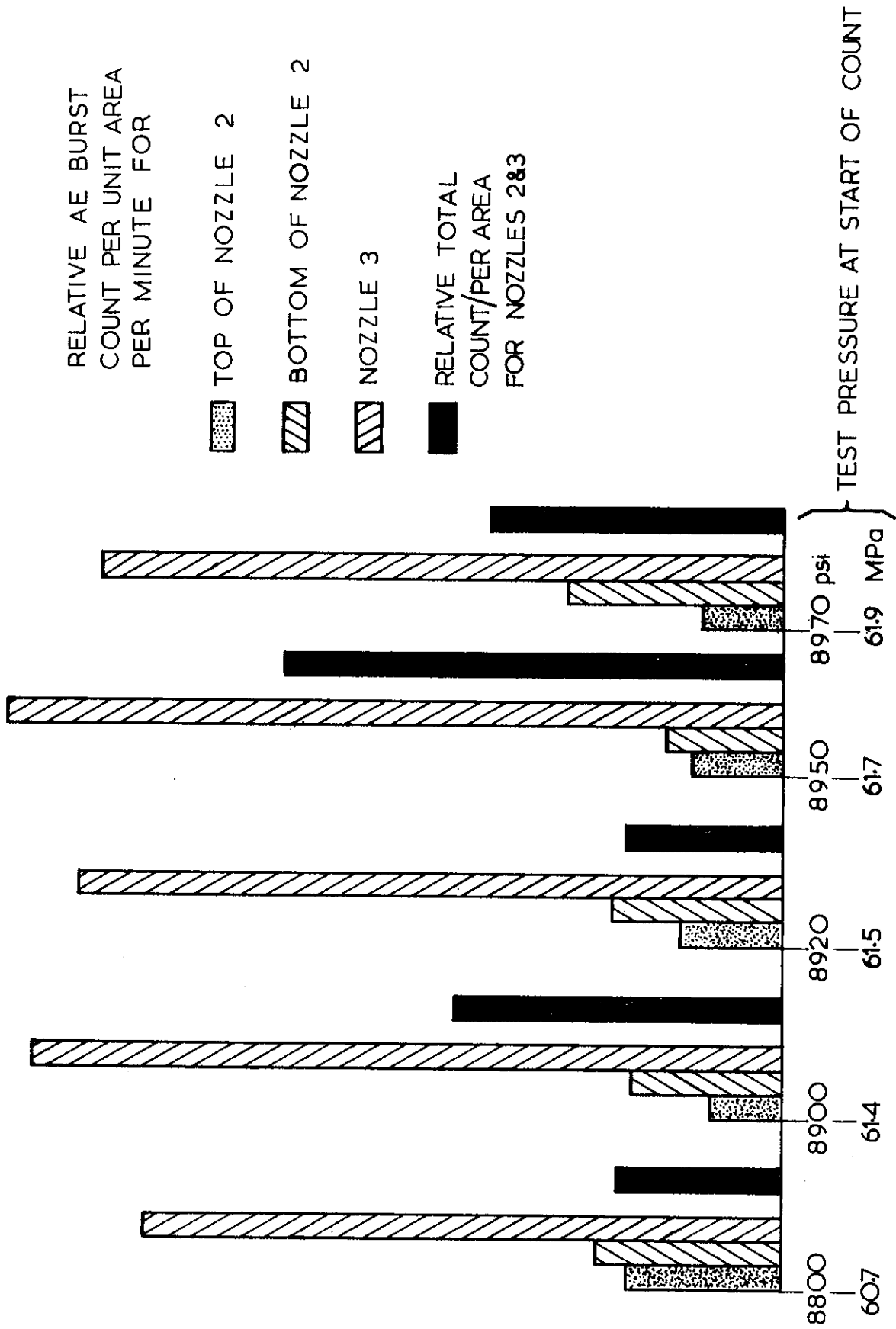


Figure 10 Distribution of AE activity between nozzles 2 and 3 as a function of time.



Figure 11 Photograph of failed vessel after removal of bunker roof.

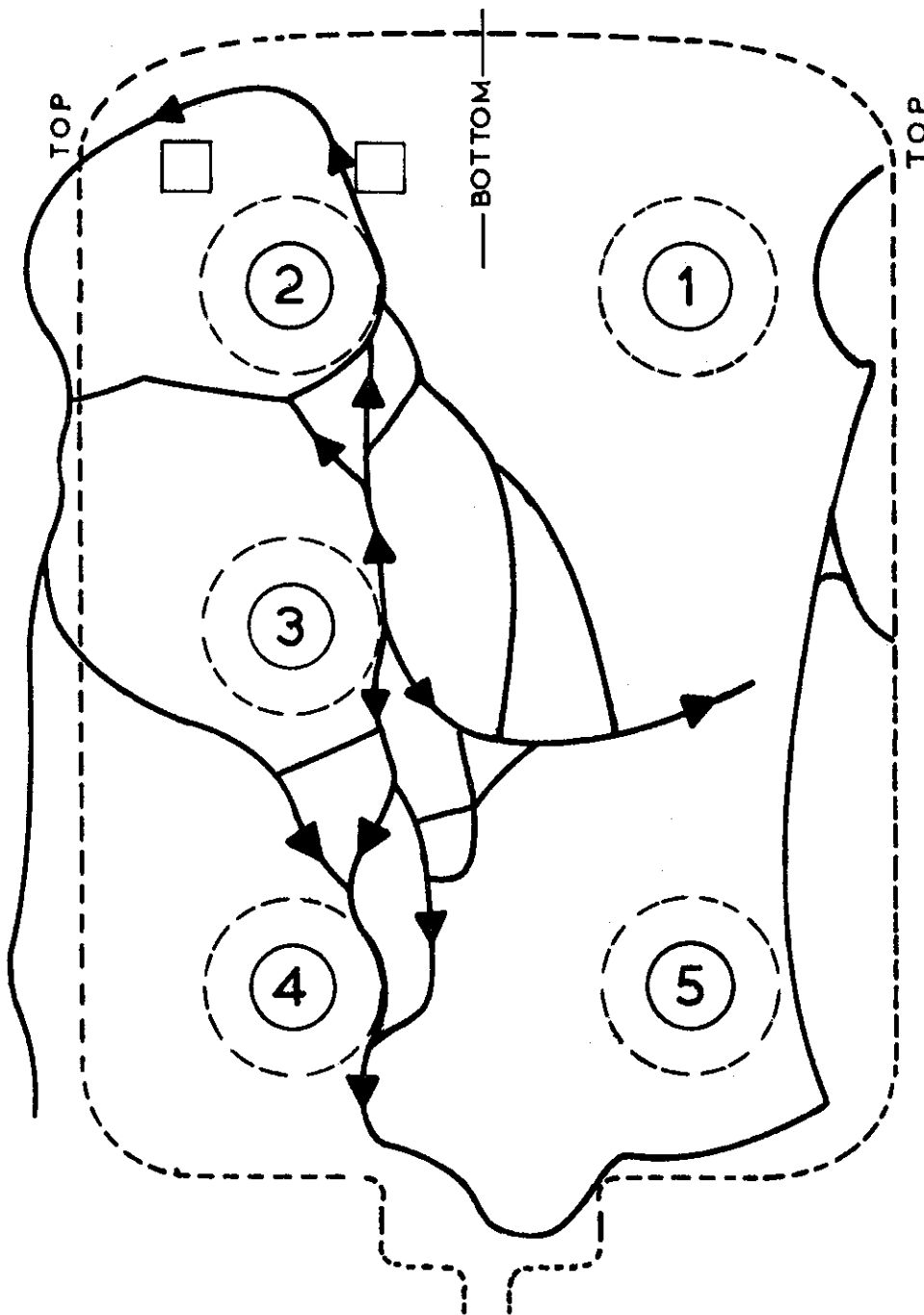


Figure 12 Development of the vessel showing the fracture paths and directions of crack propagation deduced from the fractography. (The nozzles are identified and the transducers used for location are denoted A, B and C.)

