"It may appear to be a crude method," says Mr. Wiebe. "But it gives amazing fidelity."

The strip is placed on a glass slide and introduced into a vacuum evaporator, where chromium and carbon are applied to the surface in very thin layers, the chromium at a 45-degree angle (to produce contrast) and carbon at a 90-degree angle.

A small part of this treated strip is then cut away in the area of the fracture surface in which the fracture began and soaked in a water-acetone solution to dissolve the cellulose acetate. An exact replica of the fracture surface in the form of the carbon-chromium film then remains and it is this that is placed in the electron microscope for analysis and "reading". Here, the dimples, striations and other tell-tale patterns are recognized and the mode of the fracture is determined.

One example of the application and value of metal fractography involved a hydraulic brake pipe assembly from a heavy truck. The pipe had failed and rendered the braking system inoperative, causing a fatal traffic accident. Investigators noted the ruptured pipe and it was brought to NAE's Structures and Materials Laboratory to determine the reason for the failure.

The method for producing the replica of the service component was followed and sections of the entire fracture surface were viewed in the electron microscope, at magnifications of 6,000 and 18,000. The study clearly demonstrated that half the circumference of the pipe failed by the process of fatigue. Electron micrographs showed characteristic fatigue striations, with additional evidence to indicate that the crack grew in length over an extended period. The remaining half of the circumference of the pipe's fracture surface represented the final area of breakage, likely caused by the sudden application of a single load. Elongated shear dimples visible in the electron microscope on the fracture surface are typically characteristic of this sudden shearing and tearing action caused by a single overload.

The work of the researchers, led in this instance by G.F.W. McCaffrey, also of NAE, then centred on the nature of the fatigue loads that caused the failure, and the loss of life. New components of the same type as that which failed were obtained and rigorous tests conducted in the laboratory. The actual area of failure in the service component was located at a point three-sixteenths of an inch (five millimetres) from the end fitting, which secured the pipe to the truck's wheel cylinder assembly. This end fitting, either during the process of original installation or during subsequent servicing, could be pushed back to the point at which the fracture occurred, producing a score mark on the exterior of the tubing.

"A relatively sharp notch like this may well have provided the stress concentration responsible for initiating the fatigue crack at this location in the service component," states Mr. Wiebe's official report on the matter.

Laboratory fatigue tests were employed to determine the frequency of vibration in the tubing assembly, and to attempt to reproduce the service fatigue failure. It was found that such cyclic loading produced fatigue failure in the tubing specimens similar to that observed in the service component, when studied in the electron microscope.

Instruments placed in a truck similar to that which crashed further indicated that the frequency of vibration of the tubing when the truck was travelling at 55 miles (88 kilometres) per hour — normal cruising speed — corresponded to the resonant frequency of the tubing.

The solution to the problem was simple; some form of clamping of the pipe to the truck was required in order to eliminate conditions conducive to the vibration and resonance.

The application of electron fractography to failure analysis is now an internationally-recognized procedure. The American Society for Metals is currently in the process of publishing handbooks devoted solely to fractography and failure analysis.

While fractographic techniques in certain areas are now well established, further research into the microscopic aspects of fracture is required. In general, the path of the fracture in a component passes through the region of the weakest material, in a microscopic sense, just as a chain fails in its weakest link. From this, it follows that the study of minute fractographic details represents a potentially rewarding area of research. Studies that correlate the modes of fracture with the microstructure of materials, and studies of the fracture micromechanisms of metallic and non-metallic fibre composites are already demonstrating their usefulness in the development of the more exotic materials that are demanded for low- and high-temperature, and nuclear power applications.

□ **David Smithers**