HYDRODYNAMICS

When the primary stage of a nuclear warhead is explosively compressed, components (including the plutonium core) experience extremely high rates of strain causing them to behave like fluids. The behaviour of materials under such conditions is known as 'hydrodynamics' and is actively being studied at AWE. Experiments carried out at AWE involve explosive compression of materials to observe how compression and shock waves develop and how materials behave at interfaces between components. Explosive experiments take place within robust facilities that are specially designed to contain the experiment safely. Simulant materials such as tantalum or lead are normally used in these experiments, but due to the unique properties of plutonium a small number of experiments necessarily involve plutonium itself. In these cases the amount of fissile material used is far below the quantity necessary to produce nuclear yield. As a further precaution, tests involving toxic or fissile materials are completely contained within a further leak-tight vessel made of thick submarine steel. In addition to experiments planned at AWE, complementary experiments are being carried out in collaboration with the US weapons laboratory, including some at their facilities in Nevada.

To study the movement of shock waves through the high-density material, AWE has developed a technique that uses powerful X-ray machines to record snapshots of an experiment. Other research establishments also use this method, but currently the facility at AWE is unique in operating two X-ray machines together. The facility can provide information in one of two configurations:

- **Capturing simultaneous images of an experiment along different axes provides an insight into 3-dimensional phenomena.**
- **Recording two images at different times during the experiment means that the evolution of shock waves in the material over time can be studied.**

Data obtained from the dual X-ray configuration is valuable, but it is limited because only two radiographs can be taken of each experiment. Utilising UK expertise in this area, AWE is now designing a new hydrodynamic research facility that could include up to five X-ray machines. Data from this facility would be processed to produce 3-dimensional, time-sequenced representations of the experiment.

Turbulent mixing plays a major role in the functioning of a nuclear warhead. Conditions can exist where mixing between materials either side of an interface affects overall warhead performance. An important case is a phenomenon called the Rayleigh-Taylor instability (below), which can result in surface break up and mixing of materials at the interface.

Box 4: Turbulent Mixing and Rayleigh-Taylor Instability

Turbulence is an everyday occurrence visible in the movement of water and in cloud formation and weather patterns. However, for such a well-known physical process turbulence is poorly understood. The search for a theory to fully explain turbulence has not yet provided a complete answer, even though detailed 3-dimensional models can be run using modern supercomputers and there is significant University research in the area. AWE scientists are investigating specific aspects of turbulence - one of which is known as Rayleigh-Taylor instability. A simple model that illustrates Rayleigh-Taylor instability is the implosion of a metal tube containing a material of much lower density (right).

Inward pressure on the cylinder walls cause it to implode (A). As the implosion proceeds, material inside the cylinder is 'squeezed' inwards. The interface between the two materials becomes progressively unstable, which leads to turbulent mixing of the materials (B-D). In this experiment very small random imperfections exist on the otherwise smooth interface. These imperfections grow rapidly with time as a result of the surface instability. The area and extent of turbulent mixing increases as the implosion proceeds, from the small imperfections at B to the large mixing area in D.

The issue facing AWE scientists is to model the overall effect of Rayleigh-Taylor instability on mixing and its impact on warhead performance rather than the fine detail of the mixing zone. This is analogous to predicting the weather over an area, rather than for a specific location.
3-dimensional numerical models are used to simulate turbulent mixing processes in conjunction with experimental studies to investigate relevant mixing processes.