The ZEBRA Fast Critical Facility.

ZEBRA, the zero energy breeder reactor assembly facility, was used to study the neutron physics of fast reactors (R D Smith, Nuclear Engineering Vol. 7 No. 76, Sept 1962, "ZEBRA, a Zero Power Fast Reactor"). It operated from 1962 until 1982 at the Winfrith site of the United Kingdom Atomic Energy Authority (the Atomic Energy Establishment, Winfrith, AEEW). Mock-up type assemblies representing the fast reactors PFR and MONJU and the European Fast Reactor, EFR, (which was being studied in the 1970s) were modelled, as well as simple assemblies for validation of nuclear data and methods of calculation. Some experiments were designed to validate the methods used to treat the heterogeneity of the composition of reactors and to calculate control rod effectiveness.

Most ZEBRA assemblies were built using 2 inch square plates (~5 cm square), having a range of thicknesses, stacked in stainless steel tubes, with the tubes, or elements, as they were called, being located in holes in the reactor base plate. Mini-calandria comprising a 4x4 array of fuel pins, were also used in the later assemblies. The fuel pins were composed either of uranium oxide or mixed uranium–plutonium oxide, clad in steel. The pins were surrounded in the mini-calandria by either sodium or air.

The sizes of the plates and mini-calandria was chosen to be compatible with the components used in the ZPR facilities in Argonne National Laboratory (USA) and the MASURCA (Cadarache, France) and SNEAK (Karlsruhe, Germany) facilities, permitting these components to be combined to build larger assemblies. In the "Bizet" Programme in ZEBRA, in support of EFR design, materials from SNEAK supplemented the ZEBRA materials. Many intercomparisons were made between the techniques of measurement used on these facilities and these are relevant to the assessment of the accuracy of the measurements.

In addition, special assemblies simulating power reactor control rods, control rod followers and other singularities were studied. These special assemblies replaced groups of elements.

Control rod studies and sodium voiding studies were carried out on several assemblies. Spectral indices (or reaction rate ratios), small sample reactivity worths and reaction rate distributions were measured on most assemblies. Neutron spectrum measurements were also made on several assemblies. Different techniques were used, including pulsed time of flight, proportional counters and solid state track recorders. In the later assemblies a multi-chamber scanning system was used to measure Pu239 fission rates simultaneously at a large number of points in the core.

Measurements were made on the assemblies to enable simplifications to be made in the models used to analyse the experiments. These included the replacement of ZEBRA control rods and non-standard elements by standard core elements. In the earlier cores equivalent homogeneous compositions were derived based on plate bunching measurements made to correct for heterogeneity effects. Cylindrical (and even spherical) equivalent models were also derived based on measurements of the effects of changing the core boundary shape. Later the plates were represented explicitly in the cell calculations used to derive homogeneous cell-averaged cross-sections for whole reactor calculations, including a separate representation of the cladding materials and element tubes (in a three dimensional, XYZ cell representation). The documentation enables the full details of the assemblies to be modelled.

The ZEBRA facility was housed in a cylindrical steel containment building, as shown in Figure 1. Figure 2 shows an element being loaded into the reactor and a vertical section is shown in Figure 3.

The reactor could accommodate cores, blankets and shielding assemblies with a wide range of compositions and sizes up to a 3 m cube and containing up to about one ton of fissile material (Pu239, Pu241 and U235). The component materials were stacked in thin-walled steel sheaths to form the elements, nominally about 5 cm square and 3 m long, as shown in Figure 4. The elements were located in a bed-plate and supported vertically in a closely-packed array. In later cores double elements were used which occupied the positions of two elements. These could hold instruments, such as the fission chambers of the multi-chamber system and thermocouples, more conveniently.

Enriched uranium, natural uranium oxide, plutonium metal and mixed $UPuO_2$ fuel plates were used together with a wide range of diluent materials including sodium, steel, aluminium and graphite. Lateral support for groups of 5x5 elements was provided at their tops and at two intermediate positions by thin steel lattice plates. Tubular steel-spacers inside the fuel elements enabled cores to be built at various heights above the bed-plate. Similar spacers were used to fill the remainder of the element, to prevent movement of the plates when the element was being transported.

Figure 3 shows the dimensions of the reactor regions (in feet and inches). The top of the upper super-lattice grid plate was 3 m (~9ft 10in) above the top of the bedplate holding the elements, which were 3 m long. The tops of the elements and the upper super-lattice grid plates (surrounding the groups of 5x5 elements) can be seen in Figure 2. The core sections of the elements were located between the lower two super-lattice grids, these being 100.4 cm apart and having a height of 30.4 cm and thickness of 0.25 cm.

Concrete radial shielding surrounded the assembly structure, providing a square space about 3.5 m x 3.5 m within. The vertical steel structure supporting the bedplate and superlattice grid plates is in the four corners of this square space. This biological shield included places for the temporary storage of elements and there was a corridor within it with access to the assembly from the side, as can be seen in Figure 1.

The top shielding consisted of two motorised concrete doors, which, when fully open, allowed access to every lattice position in the reactor. Hung between the doors were removable shielding blocks which permitted limited access to the core for experimental purposes when the reactor was operating. The underside of the doors was approximately 1.5 m above the top of the elements, the space between being occupied by the control rod mechanisms for the four shut-off rods which were operated from above the assembly.

A computer controlled automatic loading machine was used to load the very large numbers of plates which were required into the element sheaths, thus minimising the risks of loading errors. The markings on the edges of the plates were identification marks for the loading process and all the plates in an element had the same orientation, as shown in Figure 4.

A linear accelerator and pulsed neutron producing target, together with 50 m and 200 m flight tubes, were available for making time-of-flight spectrum measurements on beams extracted from the core centre. Spectrum measurements using other techniques were also made, both in core and in extracted beams. A view of the flight tube is shown in Figure 5.

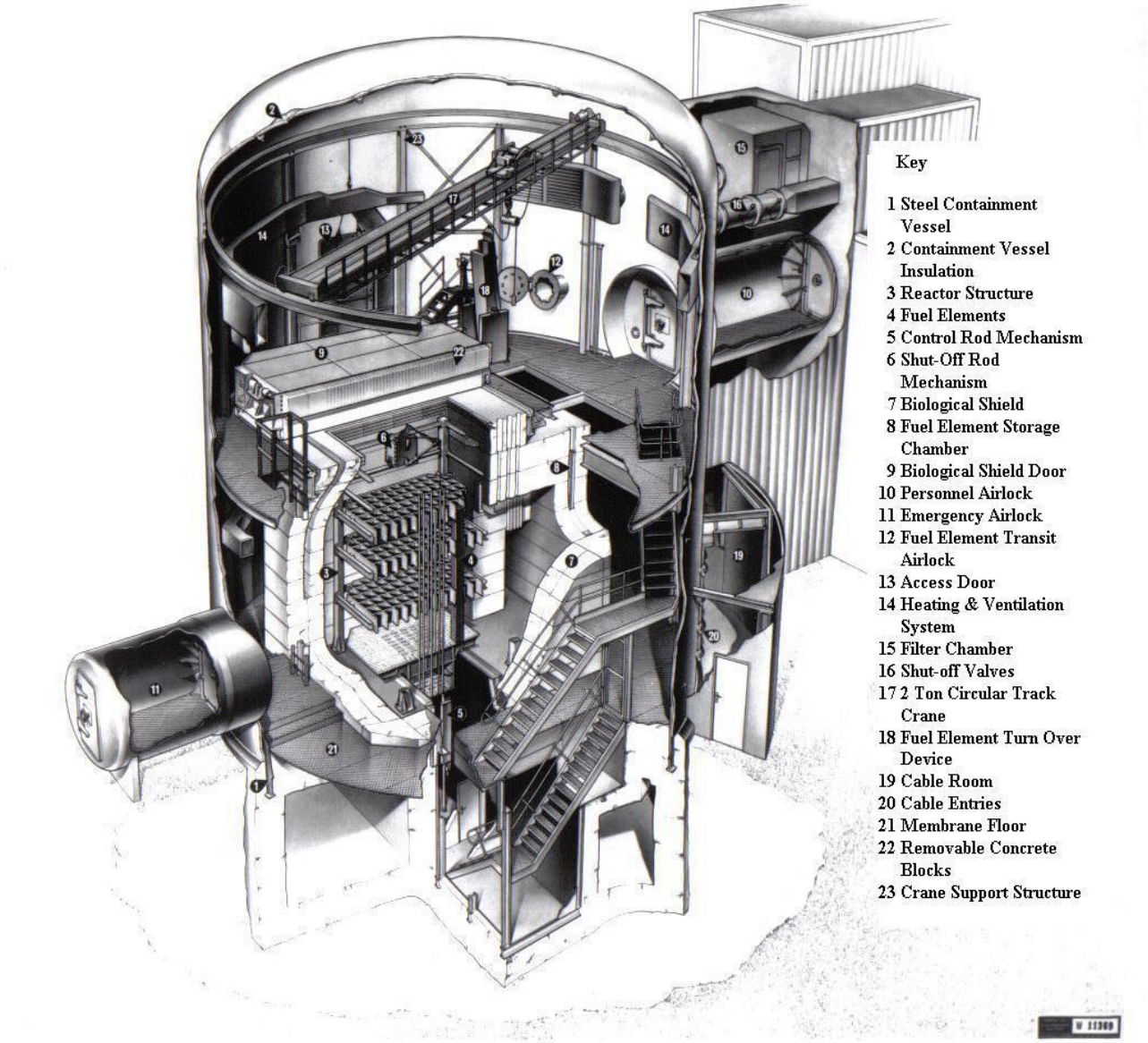

Figure 1 A Perspective View of the ZEBRA Critical Assembly Facility.
The cut-away reveals the central axial section of the facility.
(with thanks to Bernard Franklin of SercoAssurance, Winfrith, and the UKAEA, for the illustrations.)

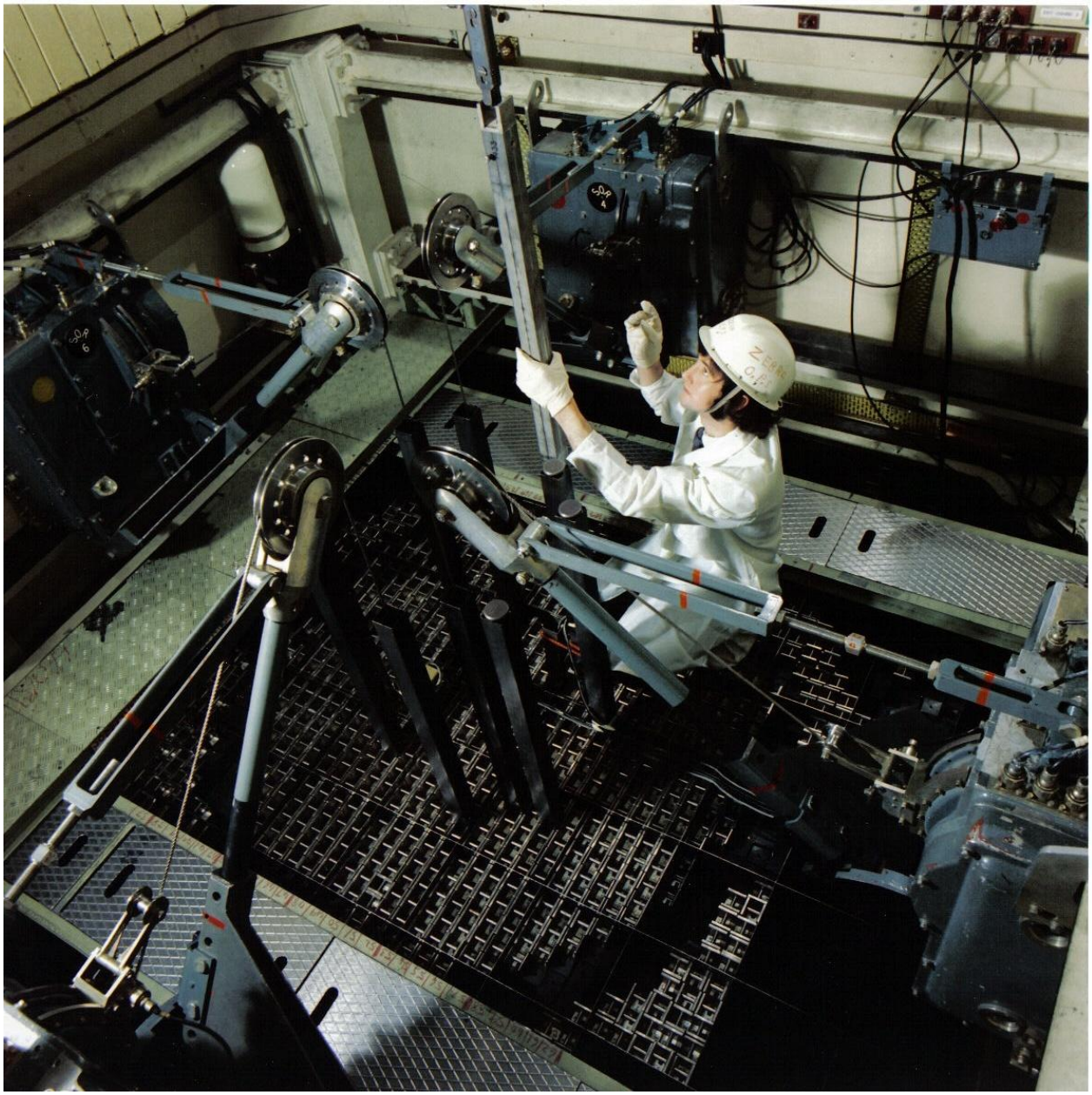

Figure 2 View of an Element being Loaded into a ZEBRA Assembly.

The figure shows the tops of the elements and the upper super-lattice grid (within which are the groups of 5x5 elements), with one element being loaded into the assembly. The cable mechanisms of the 4 control rods which are operated from above the assembly can also be seen.

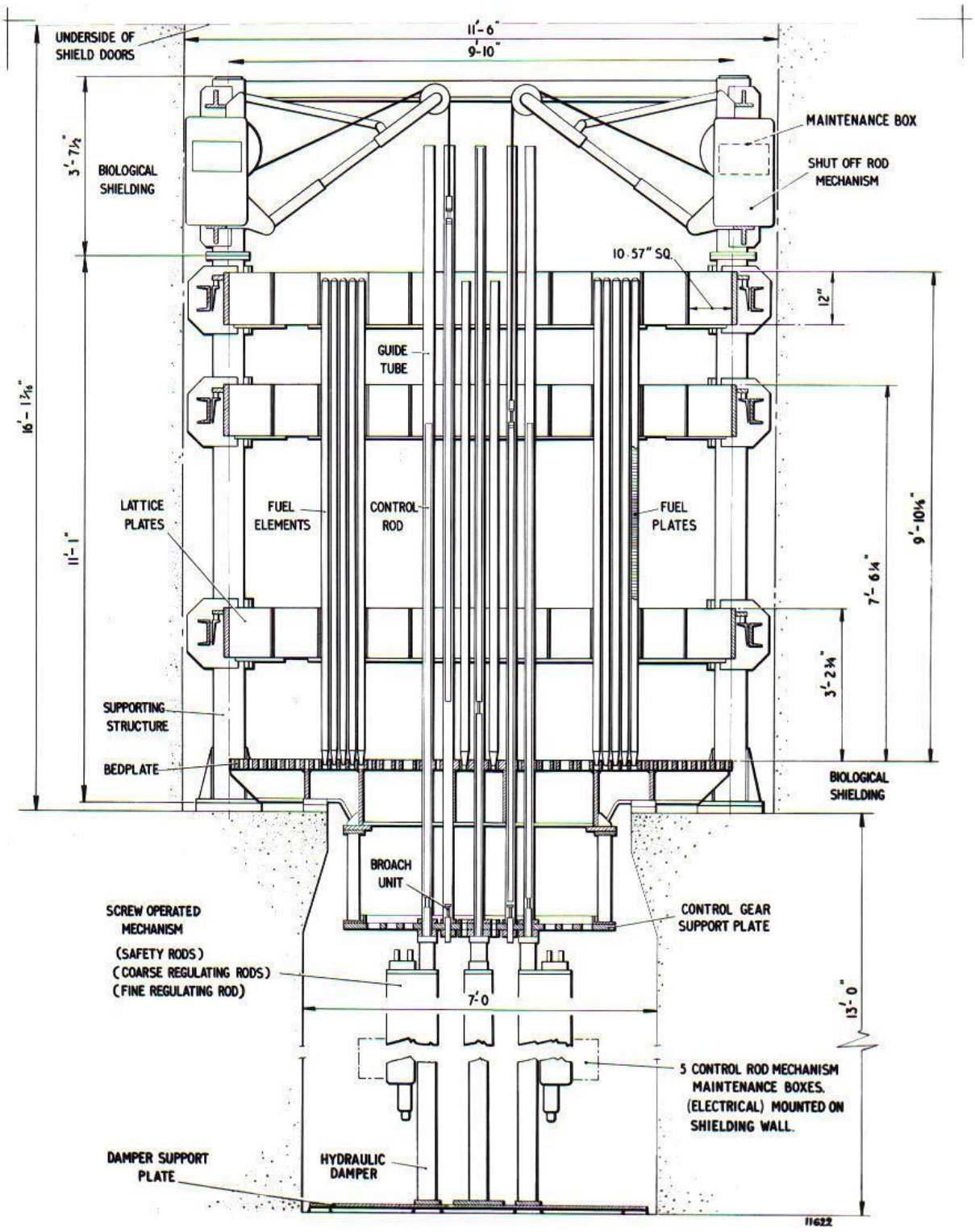

Figure 3 Vertical Sectional View of the ZEBRA Facility.

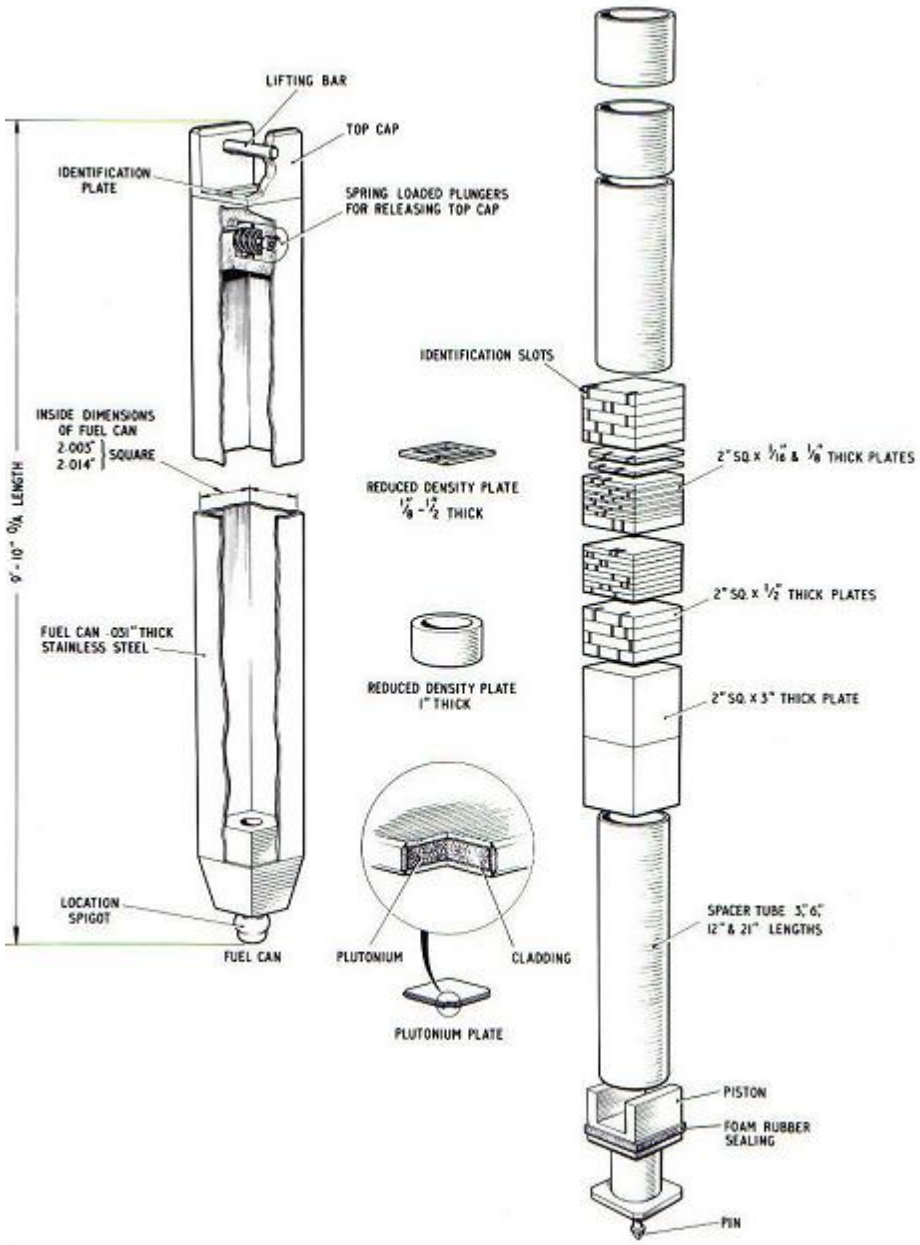

Figure 4 Diagram of a Fuel Element Containing Materials in Plate Form (dimensions in inches).

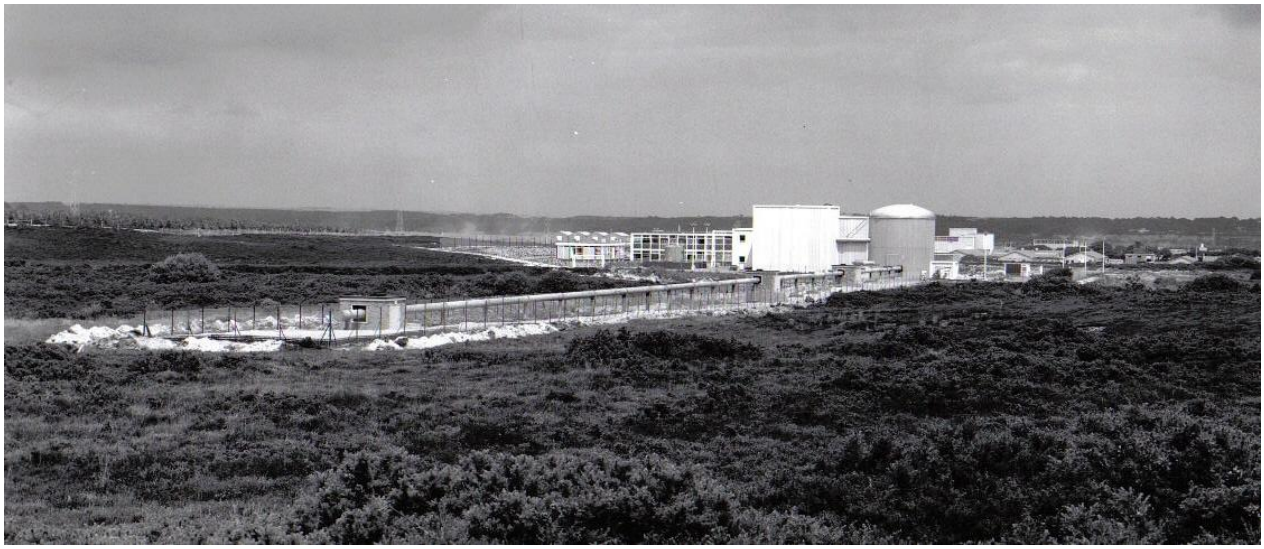

Figure 5 General view of the ZEBRA Facility showing the Flight Tube used for Time-of-Flight Spectrum Measurements.

The reactor was controlled by means of nine control rods, using two different types of control rod mechanism, as can be seen in Figure 3. Four rods, the shut-off rods, were actuated by cable-type mechanisms located above the reactor. The remaining five rods were actuated by screw-type mechanisms located in the pit below the reactor bed-plate. These five rods comprised two safety-rods, two coarse regulating rods and a fine regulating rod. When the reactor was at power, the safety rods and shut-off rods were fully raised, while the regulating rods were used to balance the power level. The locations of the control rods on the bed-plate, and their "fully raised" positions were variable. All the rods operated in guide tubes with the same external dimensions as normal elements. In some cores the control rods were double rods occupying the positions of two elements. The core sections of control rods contained a similar plate arrangement of materials to ordinary core elements with a matching fissile material content. When required to meet the shut-down reactivity requirements, as in the later cores, boron absorber was loaded above the core regions of the rods. These absorber regions were in the core when the rods were dropped.

Reactivity changes were measured in terms of the balancing changes in the insertion of regulating control rods and were expressed in terms of "standard centimetres" of movement of the reference regulating rod. A "standard cm." is the worth per cm. of insertion at the point of maximum change in reactivity with insertion. The "std. cm." was then calibrated by kinetics measurements, analysed using the reference set of delayed neutron data, to give reactivities on an absolute scale. By measuring reactivity changes which could be accurately calculated, such as the effect of changing the fissile material content of a region of the core, the accuracy of the reactivity scale could be studied, and in some cases refined.

A 10 curie radium - beryllium source was available for use in cores when spontaneous fission was insufficient to provide an adequate neutron source, for monitoring purposes when the reactor was shut-down. The source was moved into the reactor at shut-down and was motored to a position outside the reactor when the reactor was at power. The location of the source mechanism was variable.