Two examples of micromachining techniques have been chosen from among those used at the Active Fuel Examination Laboratory (LECA).

The first was a ceramic material, machined by means of ultrasonics, and the second a metallic material machined by electro-erosion and finish-machined by electrolysis.
1. Machining of Ceramics by Ultrasonics

Machining by ultrasonics is a well-known technique for ceramics. We have used an adaptation devised at the Ceramic Fuels Section, Grenoble (1).

1.1 Principle

A tool consisting of a tube of STUB steel vibrates at high frequency (20 kc/sec) taking with it an abrasive (boron carbide) in suspension in the water.

The wear due to the grains of abrasive and the low charge applied enable the steel tube to penetrate rapidly into the dioxide.

1.2 Equipment and adaptation for work in cells

The equipment is conventional (supplier - Annemasse Ultrasonics). It has an output of 120 W at a frequency of 20 kc/sec and can perform corings of 0.5 - 22 mm diameter.

1.2.1 The generator is outside the cell and has all the features necessary for the initiation, control and safe performance of machining. It is connected to the machining tool by a three-phase cable from the cell switchboard.

1.2.2 The machining tool is situated in the cell (Photo 1). Its magnetostrictor/vibration-amplifier unit is mounted on a high-precision sliding mechanism with a vertical displacement of 80 mm (counterpoise device for adjusting the machining pressure).

The depth of penetration into the ceramic is measured by a comparator to 1/100 mm.

1.2.3 The tool carrier is equipped with flat bars and is easily dismantlable. The tool consists of a tube of STUB steel 1 - 1.5 or 1.5 - 2 mm in diameter and 15 mm in length, brazed on a hexagonal cap screw.

(1) Determination of the fission gases present in irradiated uranium oxide.

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The hole of 1 - 1.5 mm diameter passes through the screw.

1.2.4 The sample is fixed in a mechanical three-jawed chuck integral with a table with micrometric movements traversed by a ball-bearing ring.

One of the three capstans can block this ring in any desired position.

An X and Y location is performed by graduated drums and index rules.

All these movements are effected by manipulators.

1.3 Mode of operation

1.3.1 The irradiated ceramic fuels are seriously cracked. In order to hold the sample together it is impregnated in vacuo with araldite and placed in a mould 50 mm in diameter (see Photo 1).

1.3.2 The sample is then polished and examined under the microscope. After it has been placed in position, the tool is brought into contact with the oxide (charge 200 g) at the chosen spot and surrounded with two or three drops of a suspension of boron carbide in water (size 320 mm).

Machining is rapid; a penetration of 5 mm takes about a minute.

1.3.3 The tool is reassembled and oscillation resumed. Sometimes the coring drops out; otherwise it is expelled from the tube by a rod.

The corings obtained are shown in Photo 2.

1.3.4 Generally localization is performed subsequently on a tenfold enlargement (Photo 3), but a sample can be taken at a predetermined spot with an accuracy of about 1/10 mm by the combined use of macrography and the table with transverse movements.
Machining on Metals

2. **Electroerosion**

The aim is to obtain accurate cuttings of samples of very complicated shapes in conducting materials with a minimum of in-cell manipulation.

2.1 **Principle and equipment**

The technique of producing an electric arc between an electrode and the sample, causing metal fragments to be torn off, is well known and is beginning to be widely used.

We used a standard Agietron machine slightly adapted for in-cell manipulation.

The electric generator is placed in front of the cell. The connecting cables pass through the front wall in a plug provided for this purpose, and provide power for the machine in the cell.

There is virtually no modification to the machine except the manual control of the downward movement of the machining head, which is repositioned at a height accessible to the manipulator (see Plate 2).

The pump-filter-decanter unit has been placed in a vessel measuring 50 x 50 x 90 situated under the working surface in order to reduce clutter. These parts are accessible and interchangeable by manipulation (see Plate 2).

2.2 **Possible applications of machining**

They are very numerous; we will mention only a few.

2.2.1 **Cutting flat tensile samples**

This work has been done on many materials, including the following:
- Mg-Zr claddings
- Structures of PA fuel elements
- Be and Zr-Cu claddings of EL-4 rods
- metallic fuels
- the hexagonal cans of the Rapsodie fuel elements
  (principle present use).

The electrode consists of two plates and two copper tubes which form the anchorage holes. We have made it demountable in order to be able to change the plates in the cell (Plate 2).

Since the start-up more than 1000 samples of this kind have been cut.

2.2.2 Cutting of compression and density samples in the hexagonal Rapsodie claddings

This forms part of the study on the bowing of steels, and is mentioned here only because it gives an idea of the rapidity and precision of this kind of work (e.g., five minutes per sample thanks to the possibility of cutting in series on a hexagon of a Rapsodie element. Samples can be positioned to within 1/100 mm (see Plate 4).

2.3.3 Coring in order to inspect the U-Mg link of annular scooped aluminium fuels

The aim is to take a sample of fuel with its internal and external claddings in order to evaluate on a traction machine the effort required to detach the cladding.

Coring is done by electro-erosion with the aid of a copper electrode consisting of a tube of diameter 12-13 mm. Sprinkling in the electrode axis is necessary.

High-precision cores are obtained in spite of the change of materials (Mg-Zr then uranium).

2.2.4 Coring for microdensity

In order to study the density variation of a metallic fuel from a gas-graphite reactor over a section, it is necessary to take samples of very small diameter, in order to localize them accurately, but of adequate length, in order that the mass of the sample may be sufficient to permit accurate weighing.
On the G2 cartridges (diameter 31 mm) we were able to take four corings on the cross-section 3 mm in diameter and 25 m long.

2.2.5 Sampling a complete gas-graphite cladding section without cold-rolling

In order to study the transverse ductility of irradiated gas-graphite fuel claddings, it was desirable to obtain a complete section of these claddings in order to perform tensile creep tests in the transverse plane. Since the fuel cans have anchoring teeth, it is impossible to slide the fuel in the can. By means of electro-erosion we were able to remove the fuel section by cutting it into six sectors without touching the can. In this way it is possible to obtain a completely intact can section (see Plate).

2.2.6 Opening of leaktight capsules without contact with the air

We mention in passing this possible use of electro-erosion for the opening under an oil bath, i.e., without contact with the air, of leaktight capsules used to irradiate samples under sodium, or deeply pitted uranium samples which must not be oxidized in air.

3. Electrolytic machining

This type of machining, based on an anodic dissolution, is beginning to be used industrially and gives very good results (speed, variety of form, surface finish, absence of stress in the neighbourhood of the machined surfaces).

Unfortunately, the equipment is very bulky owing to the high amperages and the quantities of electrolytes used, so that it cannot be adapted for use in the cell (see Note CEA-N 1.251 of Mr. BRET).

On the other hand the machining technique can be used in certain instances by making a small device adapted solely to the form of machining required.
In the LECA we have tried to use this technique associated with machining by electro-erosion.

In fact, when preparing cores of annular fuel elements, despite the finish light cracks form in the area of contact between the cladding and the uranium, and these reduce the bonding effort and hence make it impossible to estimate the value of the adhesion.

Since the cracks are very limited in extent and not deep, it is possible to eliminate them by slight electrolytic machining.

3.1 Equipment

It was necessary to have a simple, fairly compact device. It has been reduced to a cathode consisting of a copper plate 1 mm in thickness pierced by a hole of slightly greater diameter than the core which forms the anode. A jet of electrolyte plays permanently on this area.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machining voltage</td>
<td>12 V</td>
</tr>
<tr>
<td>Intensity</td>
<td>between 15 and 30 A</td>
</tr>
<tr>
<td>Duration of machining</td>
<td>2 min</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>sodium nitrate (200 g/l)</td>
</tr>
</tbody>
</table>

(see outline diagram Plate 1).

In this way a core is obtained which at scoop level has an annular groove 1 mm deep on the cross-section. The area disturbed by the electro-erosion is eliminated.

3.1.2 Anchorage for tensile testing

These same samples have to undergo a tensile test. For this purpose the external cladding is anchored in a clamp with parallel jaws. Since the anchorage on uranium cannot be affected directly with a smooth cylindrical clamp, we decided to cut a toroidal groove by means of the same electrolytic device. It is then easy to effect the anchorage by means of a cylindrical clamp with a tooth.
Conclusion

The examples of precision machining at the LECA prove the following facts:

On ceramic materials it is possible to take small samples of a few mg weight with high accuracy of positioning.

On conducting materials it is possible to cut samples of very complicated shape rapidly and with accuracy.

Where machining by electro-erosion causes faults (cracks), a supplementary machining by electrolysis gives perfectly sound samples.